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DRUM ARMATURES AND COMMUTATORS

(THEORY AND PRACTICE).

A COMPLETE TREATISE ON THE THEORY AND CONSTRUCTION OF DRUM
WINDING, AND OF COMMUTATORS FOR CLOSED-COIL ARMATURES,
TOGETHER WITH A FULL RÉSUMÉ OF SOME OF THE PRINCIPAL
POINTS INVOLVED IN THEIR DESIGN; AND AN EXPOSITION
OF ARMATURE REACTIONS AND SPARKING.

BY

F. MARTEN WEYMOUTH.

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CHAPTER I.

THE GENERATION OF CURRENT AND POTENTIAL IN DRUM ARMATURE WINDING.

As it is well, before considering practice, to understand theory, it is our purpose in this preliminary chapter to investigate the elementary theory of "drum winding." We may thus ascertain exactly in what manner the current and its potential are generated, and the "torque" set up. What is meant by this latter term may also be made clear, and certain points that are inherent with this effect may be touched upon. By the enunciation and application of known laws we shall also find that all these phenomena, under stated conditions, are but the natural results of such laws. We can then in subsequent chapters proceed to consider various methods in which theory has been put into practice; while some of the more complicated detail of theory, from its technical nature, we will leave for discussion till we have reached that more advanced stage.

Our attention may, however, first be engaged in briefly considering what are the more essential advantages that this method of laying the conductors on an armature possesses over the Gramme winding it is now to so great an extent superseding. Some of these are more or less obvious. It offers the whole area within the limits of the periphery and ends of the drum for the passage of lines of magnetic induction, as compared with the portion only of this total area offered by the Gramme ring type. Thus, other things being equal, for any given length and diameter of core, the drum will give the larger output; and conversely, for any given output, the drum armature, and with it the whole machine, can be made smaller, and so cost less than the other type. A greater radial depth of iron also can be got into the core, still further favouring the passage of lines of magnetic induction—a point of great moment. Economy in copper is also promoted, inasmuch as there is less length of conductor, as compared with the Gramme type, owing to the absence of the interior parallel conductors that exist with the latter. This consideration is, however, much affected by design, a question it is not our present object to discuss.

The accompanying diagrammatic sketch (Fig. 1) represents in isometric perspective the drum-winding of an armature and commutator, but without spindle or core, except that the last named is indicated by two lightly dotted circles. A winding of eight turns only is depicted, so that all parts may be visible, and the commutator is shown an abnormal distance from the core to avoid the complication of its covering the cross-connections behind it. This sketch represents in essence what is the more modern method of arranging the winding, particularly for heavy currents. In the earlier drum armatures, such as those of Siemens and Edison, it was the custom to connect up the different sections, not one after the other in order round the periphery of the core, but variously. This disorder of connection had the effect of preventing the attainment of a minimum difference of potential between neighbouring commutator segments, so that sparking at the brushes was not diminished as much as might be. But for constructional reasons also it is now more customary to effect the joining up, as here shown, one section after another in regular order round the armature.

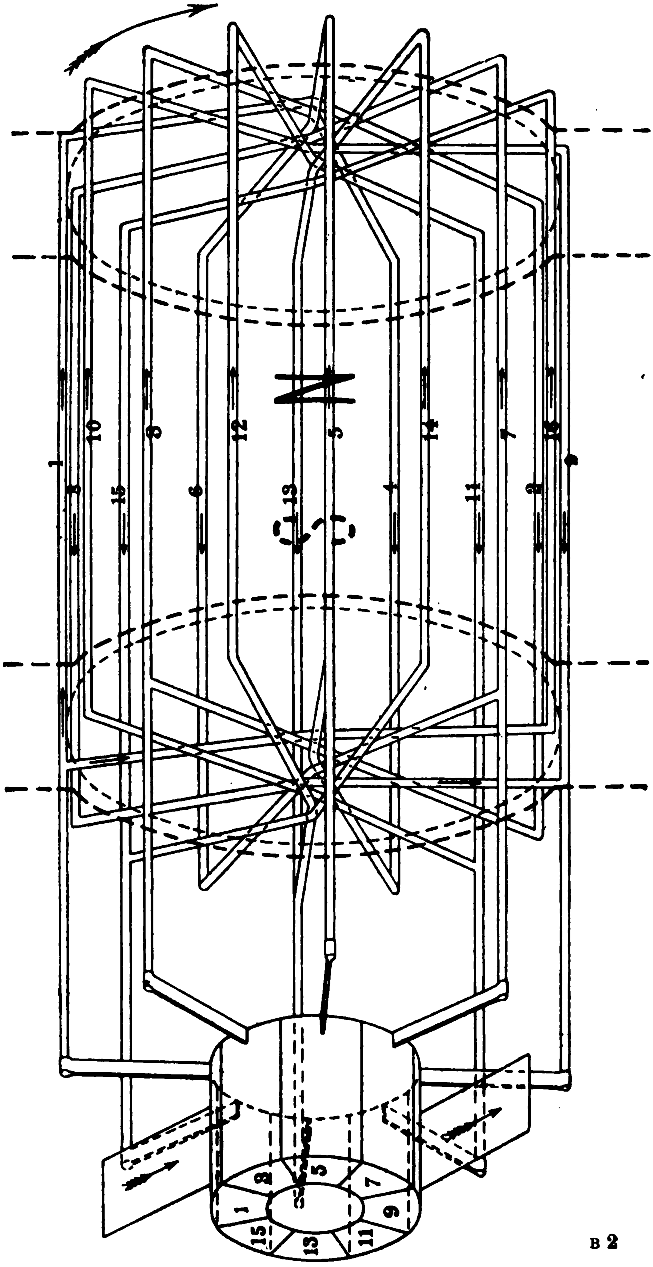


FIG. 1.—Diagram of a Drum Armature Winding.

To assist the eye in following up the connections, the parallel conductor-bars are here numbered in the order of their connection. No. 1, for instance, is joined at the right-hand end to No. 2, and No. 2 at the commutator end to No. 3, and so on, till No. 16 is united at the commutator end to No. 1 again. The bars with odd numbers alone, it will be observed, are extended to the commutator lugs. Each odd-numbered bar, and an even-numbered bar nearly opposite, with their end connections, form a section of one turn, the end of each section being joined up behind the commutator to the neighbouring odd-numbered bar, and not to its own. An endless circuit is thus formed round the armature, connected up at eight different points, corresponding to the eight sections, to eight several insulated commutator segments. Sometimes two turns per section are put in; only this, with conductors for heavy currents, involves a double series of end connections, which, according to design, may add considerably to the total length of the armature and increase the percentage of inactive copper—that is, of copper not actually cutting lines of force, and so not producing current or potential.

Now this latter reflection is by no means without importance. For it bears on all copper that may project at either end beyond the core. This subject may in fact well receive some attention, though it will be out of place here more than just to touch on it. Thus in the illustrations herewith, we have simple armature coils shown revolving in fields, the coil in Fig. 2 being short, and that in Fig. 3 long. Now it might be supposed that the coil in Fig. 3, with its extra length, whereby it might enclose more lines of force than that in Fig. 2, would be preferable to the latter. This argument would have some weight if there were no iron core in the armature. But with such a core it will not hold good. Figs. 4 and 5 will make this clear, which are sectional plans through the field, but without coils. A core is shown in

Fig. 4. The dotted lines *f* represent lines of force crossing from the one pole to the other. It will now be noted that with a core present, the lines *f* outside the field proper are few and sparse, at least as compared with the vast number that will crowd through the core. In Fig. 5, owing to the absence of a core, the total number of lines will be small; but the number outside at *f* will be much greater in proportion to the whole than would be the case in Fig. 4. Hence there might be some justification in Fig. 5 for a long coil. But, returning to Fig. 3, while in the parts of the coil lettered *c* and *d* a few stray lines of force might be enclosed, there would be practically none at all caught out at *a* and *b*. Now

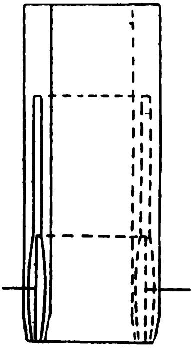


FIG. 2.

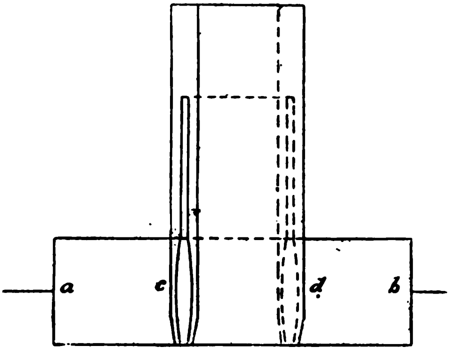


FIG. 3.

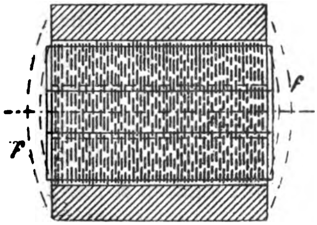


FIG. 4.

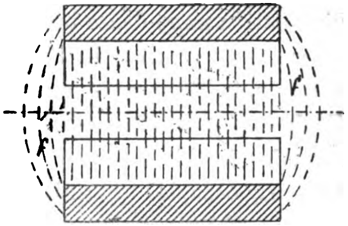


FIG. 5.

it so happens as a matter of fact, that owing to constructional reasons, which will be touched on in future chapters, the few lines at *c* and *d* usually are caught. At the same time the very small gain thus accruing would not by any means justify the expense of deliberate enlargement of parts for the purpose. It will thus be seen that, conversely, it is distinctly desirable, on the ground of expense, to keep the amount of copper at the ends of the armature as small as possible.

For many turns per section of wire winding, it may be necessary to resort to the Siemens' or other methods of carrying the wire round the ends. These, however, will be dealt with in subsequent chapters.

Reverting to Fig. 1, the coils are represented as revolving in a field between two pole-pieces, shown by the heavy dotted lines, the back one of which is south and the front north, as indicated by the large S and N, and turning in the direction of the curved arrow. The lines of force will, therefore, be going from the front towards the back, though with a normal distribution more dense toward the top and bottom, where the poles are closer, than in the middle. This latter inequality, however, is of course much modified by the iron of the core. Each section of the winding will form a loop or circuit revolving in this field; and when in a vertical position, such as nearly occupied by section 1—16, will enclose a maximum number of lines, as compared with none at all when lying horizontal. Revolving in this field, an electromotive force will be generated in the conductors.

First, then, to consider the direction of the current. We know that, according to the law discovered by Faraday, when a circuit revolves in a field such as here represented, the direction of the current will depend on two things. These are, first, according to which side of the loop the lines of force enter, and, second, as to whether, during the revolution, the number of these lines is increasing or diminishing. If the loop revolves so that when the lines are diminishing in number they enter on the side towards which the top bar approaches, then, as viewed from this side, the current will run from left to right in the top bar, and round again from right to left in the lower bar. This is the condition in our illustration, where the point of view, N, is at the front.

Now, it is obvious that during one revolution there are four different times when the conditions change. The circle of the revolution of the armature may be divided into four quadrants, defined approximately by the vertical and horizontal centre lines. The four times of change are thus those instants in which any bar of a section passes successively from each of these quadrants to the next. There is a difference, however, between the conditions at two of these instants as compared with the other two. When a given bar at the top passes from a quadrant on one side of the vertical to that on the other side and back again at the bottom, only one change takes place at each of these two instants, namely, that the enclosed lines of force that were increasing in number as the bar approached the top (or bottom) will now be decreasing in number. But at the two instants when the loop is about horizontal and one given bar passes from an upper quadrant to the one below and rises again on the other side, *two* changes take place at each of these instants. Firstly, the lines of force that were decreasing in number to zero will now commence to increase again; and secondly, whereas the lines had been entering the loop on the one side, they will now commence to enter on the other side. It hence arises that when passing the vertical position, where there is only one change of condition, this change reverses the direction of the current round the section; but when passing the horizontal position the one change from excluding to including lines of force is simultaneously cancelled by these lines commencing to enter on the other side of the loop:

hence the current is not reversed at these latter two instants. The aggregate result, therefore, is that the current is reversed only as each section passes the vertical (approximately), and is always running from right to left on one side of the armature, and from left to right on the other side. Thus, in our sketch, the direction of the current is to the right, in front, and to the left at the back, as indicated by small arrows, while those sections which are nearly vertical, namely, 1—16 and 9—8, are neutral. This approximately vertical plane is, of course, what is known as the plane of commutation, though we shall refer to this again at a subsequent period.

We have dealt so far with the direction of the current merely. We have now, however, to consider the rise of the "electromotive force," or "E.M.F.," or "potential," as it is variously termed, and without which there would be no current. This, as is well known, is proportionate to the maximum number of lines of force, or magnetic induction, passing through the section, or loop, and the speed of the revolutions. The field may be small and intense, or large and weak. Regarded more intimately as to the speed, the potential varies according to the *rate* at which the magnetic lines are included or excluded by the section. Now, as in the case before us, when these lines run horizontally, it is palpable that when the section is about vertical, the *rate* at which it is including or excluding lines is scarcely more than nominal, as the revolution through a small arc at the top or bottom makes little difference in this respect. Hence the E.M.F. generated here passes through zero value. When nearly or about horizontal, the reverse is the case, as the section is in the most advantageous position for this purpose, and excludes and includes the lines as it respectively approaches and leaves the horizontal at its maximum *rate*. Hence the maximum E.M.F. is gathered when the sections are about horizontal; but potential is also being generated in the intermediate sections between the horizontal and vertical. Theoretically, the E.M.F. generated in any one of these varies not with the angle but with the sine of the angle which its plane makes with the vertical plane; or, in other words, varies directly with the horizontal distance of its bars from the central vertical plane, similarly as the number of magnetic lines enclosed varies with the vertical distance of the bars from the horizontal plane. It must be clearly understood that the foregoing refers only to the *generation* of the potential in each several section, as the potential that may actually exist in any section at any instant may be very different from that which it is itself at that instant generating.

We may now consider the course of the current round the winding, together with its accumulation of E.M.F., and its delivery to and return from the outer circuit. Referring to our sketch, Fig. 1, it will be observed that the brushes touch on the segments of the commutator connected to bars 1 and 9. To commence with bar No. 1, we immediately remark that this, being in connection with the upper brush, and the current in it running from left to right, the current from the outer circuit will here be entering, and the upper brush will be the negative brush of the machine. In this bar 1 there will be the minimum potential, and from its approximately vertical position it can generate practically none. The current running to the right passes across the end to bar 2, thence to the left and across again to bar 3, accumulating E.M.F., and so through sections 4—5, 5—6, where it practically gets its greatest amount of E.M.F., through 7—8, and to the left-hand end of bar 9. This latter being connected to the segment whereon the lower brush makes contact, the current will here pass to the outer circuit, and this brush will form the positive pole of the machine. But the total current and potential difference here, it will be observed, are what has been accumulated in the sections represented by bars 3, 5 and 7 only; and these form but half the winding, not reckoning neutral sections. We have now to account for the other half. Returning to bar 1 again, this, with bar 16, forms a section about vertical, and consequently neutral. The right-hand end of the latter bar (16), however, is connected across to bar 15 on the further side, where the current is in all cases running from right to left. Hence, whereas one-half of the incoming current passed along the length of bar 1 and so to bar 2, the other half will cross to bar 16 at the commutator end, and thence into the series of sections 15—14, 13—12, 11—10, gathering potential on its way, on to the right-hand end of bar 9, and so to the lower brush, *together with* the current entering that bar at its left-hand end. Thus the current, entering at the left end of bar 1, has two paths in parallel which it may follow throughout the two series of sections which alternate with one another round the armature to reach the positive brush; but the potential accumulated in each of these series is the same. Hence, as when two pipes of similar diameter delivering water under the same head (or pressure) unite in one common pipe, the pressure may remain the same, but does not increase; while the amount of water delivered, or the current, is doubled:—so the current delivered at the lower brush is equal to the currents of both series of sections added together, or twice that of one of them; while the electromotive force is not doubled, but remains only such as is accumulated in either one of the series. Consequently, in calculating out a drum winding it is requisite to obtain the total area enclosed by the several sections of one series only, to ascertain the electromotive force, while the section of the bars need be but half that necessary to carry the whole current of the machine. It will be observed here, in accordance with a remark we have already made, how that, although there will be little or no potential *generated* in sections 9—8, 9—10, yet the potential actually existing in these is the aggregate potential of the series to which they each belong. It may appear paradoxical that in the case of the second series the potential should be rising on its way down the further side in bars 15, 13, 11, and correspondingly up the front side, in a contrary direction to that in which the armature revolves. But this is the way the current goes in this series of sections, and it naturally forms its "head," or point of highest potential, at the end towards which it is tending.

We have thus far shown how the E.M.F. and current are induced. There are, however, some further points in this connection to be referred to. The first which may be mentioned is one of no little importance. It will be remembered that the long bars down the sides of the armature have an increasing potential in their order from top to bottom; consequently and inversely, their respective short bars opposite have a potential increasing from bottom to top. It follows that in all cases where the sections are about horizontal, the currents in their respective parallel bars on both sides are of about the same potential; but at the top the short bars of the high potential come alternately with the long bars of low potential, and *vice versâ* at the bottom,—the differences of potential increasing gradually from the sides toward the top and bottom, till at these latter points bars of maximum and minimum potential are lying adjacent. This constitutes an inherent evil of drum winding which cannot be eliminated. Another point to which attention may be drawn concerns the brushes. Should these be slipped round so as to come on the segments of the commutator 7 and 15, instead of 9 and 1, it might appear at first sight as though the current would be reversed in the outer circuit. But it would not be so, as the current would be reversed in bars 8 and 7 and 15 and 16 instead. In other words, the sections to which bars 7 and 15 belong would for the time become neutral, and the current continue to flow out at the lower brush, inasmuch as the pressure or potential in 7 is higher than that in 15. But as, according to the principle already enunciated, whereby the highest potential must be at the bottom of the vertical plane of commutation, the effect of moving the lower brush on to 7 is simply to take it from a place of higher potential to that of a lower, with the further effect of reducing the potential of the outer circuit in proportion.

We have, when mentioning the plane of commutation, alluded to this as only approximately vertical. It is in this connection that the polarisation of the iron core of the drum may now be considered. According to Ampère's well-known rule, the direction of the current round the horizontal sections of the winding will induce a north pole at the top of the core and a south pole at the bottom. With regard to the sections more nearly vertical, we may assume the plane of commutation to be exactly vertical, and so the bars 1 and 9 in our illustration to be exactly at the top and bottom respectively. We then observe that section 10—9 tends to produce a north pole on the *further* side of the core, while section 15—16 tends to produce a north pole on the *front* side; hence these two tendencies counteract each other. Intermediate sections, however, such as 11—10, 15—14, will tend to produce a north pole, the one on the further side of the top and the other on the nearer side. Hence the ultimate result will be a broadening of the poles at the top and bottom. This polarity, with poles in the plane of commutation, is known as the "self excitation" of the armature. In respect of the field, however, it is called "cross induction." But we shall enlarge on this in a later chapter. The effect of the magnets between whose pole-pieces the armature revolves is to induce poles at the *sides* of the armature, a north pole on the further side and a south pole on the front, at right angles to the self-polarisation of the armature. Experience has shown that it is desirable to magnify this effect, and to make the enclosing magnets so powerful that they shall almost entirely overcome the self-polarisation of the armature. Hence ultimately, by a compromise, the north pole of the core becomes located a little above the horizontal on the further side next the S pole-piece, and the south pole of the core a little below the horizontal on the front side opposed to the N pole-piece. A plane joining these two poles will form a centre plane of the lines of force of the field passing through the core; and the tilting of this plane represents what is termed the "distortion of the field." The joint centre plane of the ultimate polarisation of the core and the field being thus a little tilted, the plane of commutation, which, as already explained, must be normal to the field, becomes tilted also, determining the lead of the brushes. That is, the plane of commutation becomes tilted, not as a direct result of the tilting of the self-excited polarity of the armature, but because of the tilting or distortion of the field.

A remaining point for discussion in this present chapter is the *torque*. By this is meant the tangential pull on the armature tending to prevent its rotation, and requiring power to overcome it. In the case of a motor it is the turning moment by virtue of which it revolves, and performs work.

Now this torque is the result of the attraction between the *self-excited* poles of the armature and the poles of the field magnets. For, apart from the polarity of the core caused by the armature coils, there would be no torque. The polarity of the core induced by the magnet poles has no tendency to produce torque, as the strains thereby set up are in a line with a diameter through the core; and the magnet poles have, in fact, no joint tendency to move, or prevent the motion of, the armature in any manner, inasmuch as the opposing poles attract it equally in opposite directions. It may be said that the torque is an effect of the contest between the polarity of the core induced by the magnets and that caused by the armature coils, whereof the result is that they amalgamate, as already intimated. And the extent to which, in their amalgamation in any given case, the self-polarity of the armature distorts the polarity induced by the magnets, is the measure of the torque.

In different cases, however, with any given torque, the distortion may be large in some and less in others. The strength of the self-polarisation of the armature depends on the total amount of current traversing its coils; while the strength of the polarity induced by the magnets depends, of course, on the strength of the magnets. Hence, in one case the armature self-excitation, due to a large amount of current in its coils, may be stronger in proportion to the field than in another where the total armature current may be less in proportion; and the distortion in the former will be more than that in the latter, and the brushes require more lead. In any one case, however, the torque may be increased by increasing the armature current, when the distortion will also become greater; or it may be increased by strengthening the magnets, which will decrease the distortion. In the latter case there will thus be the paradoxical result that with more torque there will be less distortion.

But, though the armature revolves, its poles do not go round with it. This may seem difficult to understand, and may be explained as follows. It will be borne in mind that the polarising effect of each coil is only as detailed above *when it is in the particular position referred to.* Directly any one coil has moved into the position previously occupied by another coil, it has assumed all the characteristics which the other coil had when in that position. The characteristics, in fact, appertain to the *position per se* only being affected by those laws which govern the nature of the current as a whole; and do not follow the coil in its rotation. Now this being so in the case of individual coils, it follows that it is so with all. Hence the polarising effect of the whole—that is, the armature poles—remains stationary, though the armature itself rotates. The reason of the persistence and continuance of the torque will also now be the more apparent, inasmuch as it is obvious that, if the poles of the armature continue in opposition to the poles of the field magnets in the manner already shown, the mutual attraction between them, which forms the torque, must also remain.

It is necessary, however, to examine this subject yet more closely. For, although—disregarding the effects induced by the field—the iron of the core becomes polarised, the coils themselves *en masse* have a resultant polarity, apart from the existence of, though coincident with the polarity of, the iron core. That is to say, if the iron were removed, the north and south poles of the winding would remain just the same, in mid air, as it were, though reduced in strength. Hence the upshot is that, though the core will experience a torque on its own account, due to its magnetisation, yet the coils also will experience a torque tending to prevent their rotation, apart from that on the core. As a consequence—and this is the important point—whereas the torque on the core is met by its being firmly keyed to the shaft, provision is also needed to meet the torque on the coils; and they must be so secured to the periphery of the core that when the latter is revolved they must go with it, without any possibility of circumferential creeping.

This latter contingency, that is, the peripheral creeping of the conductor bars, is by no means so unknown as might be supposed. For especially in the case of motors, if the conductors are held only at the ends of the armature, as, for instance, between teeth on the end plates, they will bend in the middle. Binding wires wound round outside may prevent their flying off; but howsoever tightly they may be bound on, the bars may none the less creep circumferentially under them, unless mechanically stopped from so doing by means of projections from the core.

Having thus far treated of the theory of drum winding, we may in the next and subsequent chapters proceed with the consideration of the various methods in which theory has been put into practice.

CHAPTER II.

WIRE DRUM WINDING: SIEMENS.

Various methods have been adopted from time to time by different inventors and makers to put drum armature winding into practical shape. Among the many points for consideration that occur, perhaps the most prominent is that involving the question as to how to take the cross-connections at the end of the armature round the spindle. It is thus of interest to observe, for one thing, in what different ways this particular difficulty has been surmounted, and "the end-winding," as it is termed, arranged. It may be true that in the case of armatures for small currents, and wound with flexible wire, this difficulty may not be very great. But in dealing with heavy currents and conductors of large section, it is different, and many points of mechanical construction arise for consideration. It is with these we shall be mostly concerned in the course of our remarks. We may state here, parenthetically, that though some of the sketches that accompany this chapter are taken from designs actually carried out, the others will merely illustrate principles of design without pretending to be actual representations of any particular machines. Further, it may be added that we shall confine ourselves almost exclusively to armatures for two-pole machines.

Dealing for the present with wire-winding for light currents, we meet with the most simple and crude of all armature winding in Siemens' wire wrapping. This winding consists fundamentally as shown in Fig. 6; and, supposing a single turn per section, in merely carrying the wire from one commutator segment along the periphery of the drum parallel with the axis, across the further end, giving it a slight bend to one side to get past the spindle, and so back again on the other side, repassing the spindle, and then joining it to the next commutator lug from whence it started, or in irregular winding to some other lug. In practice, however, the wire may be carried round many times before being joined up to the lug of the next commutator segment. Each "section" of the winding is thus said to be composed of so many "turns"; and while there may thus be any number (within reason) of "turns per section," there are as many "sections" as there are segments in the commutator, neither more nor less. All the turns in a section may lie in approximately the same plane, carefully insulated from each other, and each section likewise from neighbouring sections, and from the core. There may hence be in a winding of this sort a large total number of turns of the single wire; and as the volts depend for one factor on the aggregate of the areas

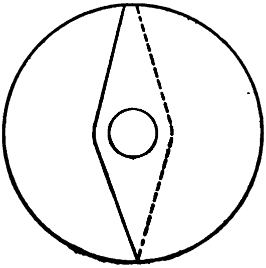


FIG. 6.

enclosed severally within half the number of these single coils or turns, it will be seen that this form of winding is particularly suitable for small currents and a high pressure, for a few amperes but many volts.

It will now become obvious that in a fully wound armature of this sort, especially when the wires lie in two or more layers on the periphery of the drum, there will be a great accumulation of wire at each end, giving the ends of the armature a more or less hemispherical shape, where the coils overlie each other, as shown in Fig. 7. The current courses round the armature in one section as many times as there are turns in it, thence to a commutator segment, whence again, supposing the segment not to be in contact with a brush, to another section. Now, as each turn round the armature means virtually the opportunity of acquiring potential, a considerable difference of pressure accumulates between each section as a whole, and so between each commutator segment, rendering special care necessary as to their insulation.

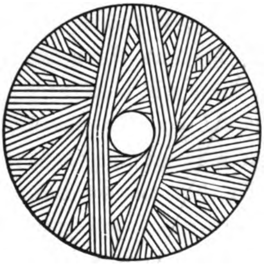


FIG. 7.

But now, instead of each section of the winding being composed of one long length of wire carried round many times, the several turns being "in series" with one another, let us suppose that each "turn" consists of a separate wire, and the "section" a group of wires all carried round together, with all their ends at one end of the section connected to one commutator lug, and all the other ends to another lug. The several "turns" would now be connected "in parallel." The current, instead of being able only to flow through the turns one after the other, would now flow through them all at once as they lie side by side, and thus would go only *once* round the core lengthways between any two segments of the commutator. The effect will hence be noted. The aggregate of the areas enclosed within the several "coils," as we may now term the sections, being considerably reduced, other things being equal, the volts will be proportionately reduced; and as the current is able to flow through all the wires in a coil at once, it meets with less resistance—the resistance depending for one thing on the sectional area of the conductor—and there will be a large current; in a similar manner as there would be a greater flow of water under a given head through a large pipe than through a small one. We thus find, in fact, that the conditions as compared with the former case are reversed, and we have many amperes, but few volts. It will be necessary to provide a larger commutator; for while the number of segments remains unaltered, these must be of a section sufficiently large to carry the now heavy current, and of a length sufficient to afford room for a suitable number of brushes to take it off.

But to return once more to the former case of many turns per section, we may consider briefly some of the merits and demerits of this particular form of winding apart from its adaptability for heavy currents. As is well known, and fully explained in Chapter I., the current in its course through the armature winding pursues two paths from brush to brush; in fact, as it might, supposing it were possible to remove the core, and pull the wire all out into one large circular loop with the brushes on the opposite ends of a diameter, when the current would be able to flow along both sides of the loop from one brush to the other. Now, with too great a density of current, the conductors are liable to heat. Let us consider this point. Take the case of two pipes conveying water, one, say, 4in. diameter bore and the other 2in., and let us imagine the same delivery through each. Now, as the sectional areas of the two bores—or, in other words, of the fluid cylinders in each—will vary with the square of their diameters, it follows that the velocity of the water in the small pipe will be $2^2 = 4$ times the velocity in the large pipe. Confining ourselves to slow velocities (as with high velocities the analogy will not hold good, for hydraulic reasons), and imagining a long length of piping, we find that besides there being in the first place the necessity of four times the head or pressure to produce the higher velocity in the small pipe, there will be a still further increase of head necessary in the case of the small pipe, on account of the increased friction between the water and the internal skin of the pipe due to the higher pressure. Thus the point to be noted is, that in this small pipe, as compared with the large, we find there is a waste of energy incurred due to this friction. If this be carried to an extreme, and an attempt be made to still further increase the delivery, the small pipe may end by bursting. Now, returning to our electric conductors, we find this analogy holds good. If it is attempted to force more than a certain quantity of electricity per unit of time through a given size of conductor, there will be similar waste of energy; only, in the case of the electric current, this will show itself by the rise of temperature of the conductor; and this waste energy, in the form of heat, will be dissipated by radiation or convection. As the heating of the conductor will decrease its conductivity, there will likewise need to be a corresponding increase of pressure or potential. Similarly, also, if matters be carried to an extreme, and it be attempted to make the wire carry an undue amount of current, the wire will simply melt, or even burst, with a sudden increase of current, owing to the inside of the wire melting before the outside, and thus expanding quicker.

Now, an accident that is liable to happen to a dynamo is what is known as a "short-circuit." The current from the machine under ordinary circumstances has open to it a course only through an outer circuit, of lamps and so forth, offering resistance to its progress. If, by some mischance, however, such as a wire or piece of metal falling across the positive and negative terminals of the switchboard, connecting them electrically, a much easier way of getting from the one terminal to the other will be open to the current, instead of its having to go through all the circuit with the lamps; in other words, the resistance of the outer circuit will be practically eliminated. There will be a rush of current which the armature will not be able to withstand. The armature winding will heat, and may get red hot, and perhaps even melt. The insulation is destroyed, and metallic connections thereby set up which are fatal to the proper action of the machine. The result of a bad short-circuit is, therefore, that the armature is rendered useless, though often only one or two or a few of the sections are burnt, the remainder being uninjured.

Recalling our attention now once more to the wire-wrapped drum armature, from which we may seem to have wandered, it will at once be obvious that with the overlay of the wrapping at the hemispherical ends, to renew a few burnt sections, especially if these should be among the innermost, the whole must be unwound, involving expense and trouble. This is thus one of the principal drawbacks of this form of drum-winding, though not altogether peculiar to it. Another drawback lies in the fact that it is not possible, with this form of end winding and so much crossing of the wires, to prevent the close proximity of wires of high and low potential. Hence especial care is necessary as to insulation. Again, the combined heating of the wires at the ends where they lie in such a mass is not so easy to prevent, or to mitigate by ventilation, as when arranged differently. It has its merits, however. Each section of the winding, of howsoever many turns, is whole throughout its length, without joints, which involve labour and expense to make, and form possible sources of resistance. It is in some respects easy of construction, dealing only with flexible wire. The fact also of its allowing of many turns per section as compared with most other windings, gives it a distinct advantage for obtaining high volts out of a small machine without the necessity of an inconveniently high speed—when a small current only is required. This point may indeed, perhaps, be considered as its most valuable feature.

CHAPTER III.

HEAVY WINDING: DIFFICULTIES AND PRELIMINARY CONSIDERATIONS.

We may now, however, proceed to the consideration of armatures wound not only for high volts, but also for a heavy current. The chief difference between these and those we have discussed is that the conductors must be of a much larger section than that of mere wires, and will, in fact, become "bars" rather than wires. Before going on to describe any particular heavy current winding, however, it may be advantageous, perhaps, first to consider some of the points that have to be borne in mind when getting out the design of such a winding. These naturally fall under the heads of efficiency, economy, and practicality. The question of efficiency, however, in this connection, is mostly disposed of in the fundamental calculations of the machine. Granting, then, that the sections of all the conductors are of sufficient size to carry the intended current without undue heating, it is a matter of contrivance so to arrange these on the armature that while the greatest economy in labour and material is aimed at, efficiency shall not be sacrificed. It thus becomes an object in designing an end winding, while retaining the necessary cross section, to aim, for economy's sake, at a minimum total length of copper. Compactness is also required, so that the winding may project the smallest amount possible beyond the ends of the core. As these parts of the winding generate no current, there is no object in their enlargement; while compactness assists not only economy in the copper itself, but also, by keeping down the total length of the armature, the total length of the machine as a whole is kept down, together with its weight, first cost, and floor space, minimum floor space being frequently a desideratum, especially on board ship. But while aiming at compactness, ventilation must not be forgotten, especially in the case of large machines, though there are makers who do not attach the importance to this point that others, probably the majority, attach to it. Again, it is well to have as few joints as possible in the coils; as these, depending on the human factor for their perfection, may be faulty, and so cause resistance. The extra labour and expense incurred in making them must, moreover, be remembered. An armature should not be too complicated, so that its construction may be comparatively easy and straightforward; and all joints should be accessible. Labour is thus economised; besides, by avoiding work that is at all "fidgety," dependence on a few special men who may acquire the particular aptitude necessary, and whose services may be lost in a strike or otherwise, is avoided. With this last desideratum is in some degree involved another point of importance, which is, that parts burnt or otherwise damaged may either be removed and replaced with facility, or else that the whole winding should be capable of being easily dismounted and put together again for the same purpose. The conductors, as explained in Chap. I. (pp. 15, 16), require to be well held on by steel wire wound round in bands outside, circumferential slipping being still further prevented by projections from the core and end plates. For it will be borne in mind, that by virtue of the work done in driving the armature, the parallel conductor bars are subjected to a magnetic drag or torque tending to hold them back from revolving with the core and spindle; and this drag is no light matter: hence the necessity of fixing the coils well. To this magnetic drag is added the centrifugal force tending to make the coils fly off altogether.

There are, however, still some two or three other points that require attention. Of these, one is the question of a true balance. It is necessary to put on the winding and form up the ends with such symmetry that the centre of gravity of the whole armature when complete shall be in the axis of the spindle, and not outside. Now, in ordinary practice, the armature, when finished, is tested for balance by being rolled with its spindle at each end resting on two horizontal "knife-edges." If the centre of gravity of the whole be in the axis, it will rest in any position; but if not in the axis, the armature will then roll, oscillating backwards and forwards till it rests with the heavy side downwards, when extra weight must be soldered or otherwise be attached to the light side till a balance be attained. But it has to be noted that this is not really a true test. It is a question whether or not armatures are sometimes made having the centres of gravity of their two ends, taken separately, not in the axis, though equi-distant on opposite sides of it. A fault of this nature would not show on the knife-edges. But when revolving rapidly, there would be a tendency in an armature thus faulty for its axis to gyrate round the true axis of revolution in two cones, one at each end, having their apices united at a point within the true axis somewhere between the two misplaced centres of gravity. Hence a greater or less tendency to vibrate will still exist, though the armature might show a perfect balance on the knife-edges. This kind of error might, perhaps, be detected by mounting the armature within a magnetic field, on bearings supported on flexible standards, or, better still, on bearings slung from adjustable springs, and then, with brushes lightly touching the commutators, revolve it as a motor. If the balance be true, with the centre of gravity of each end within the axis, the armature, when rotating at a tolerable speed, would evince a tendency to maintain a constant and steady axis in any one position, like a gyroscope. But if the balance be out of truth in the particular manner under discussion, a decided desire to "wobble" would show itself.

Another reason, however, for being careful as to symmetry, is to secure the perfect roundness of the exterior circumference of the completed winding, with its centre within the shaft axis. The clearance between the armature and pole-pieces may thus be kept to a minimum. Further, by attaining exact similarity with all the coils, in length, section, shape, and position, their resistance and self-induction will also be similar, tending to a steady current and an absence of sparking.

A remaining, and very important point, however, that arises, especially in connection with heavy-current windings, is the liability of the conductor bars to heat by reason of "Foucault" or "eddy" currents generated within them individually, apart from the main current. These we may explain: In some kinds of dynamos other than those with drum or Gramme armature—such, for instance, as those used for alternating currents—the coils, instead of being *revolved* in a field, are *translated* across a field edgeways. In other words, the coil is so placed that its plane is perpendicular to the lines of force of the field; being still kept in this plane, it is moved across the lines of force, and so cuts them. A current is thus set up in the coil. Now, if instead of a flat coil, a flat metal plate were used, and were made to cut through the field edgeways in a similar manner, a current would be caused to circulate in the plate in a plane perpendicular to the lines of force, this, indeed, being much the principle of Faraday's first disc dynamo. If the plate were turned so that its plane were parallel with the lines of magnetic induction, and then moved through them, no current, comparatively speaking, would be generated within it. This point is important. Now if, again, instead of the plate, a single metal bar be moved sideways across the field in a plane normal to the lines of induction, a current will arise within the bar; and this current will circulate within the bar in planes perpendicular to the lines of force, running along one of the sides parallel with these lines and returning by the other. Thus it is obvious that as a current will produce heat, if the experiment with either the coil, the plate, or the bar, be carried out to any great extent, and they be moved rapidly and continuously through a sufficiently strong field, they may be made red hot; and the fact remains that if a single insulated bar be laid along the periphery of an armature parallel with its axis of rotation, or held in a frame, and then revolved in an ordinary magnetic field, such as used for drum or Gramme dynamos, it will get hot from these internal currents alone.

But in dealing with large "bars," however, there may also be borne in mind their capability of cooling as compared with wire, or bars of small section. It will be noted that whereas the transverse sectional area of a bar increases with the *square* of its diameter if round, or as the *square* of the side if of square section, the circumference or outer surface increases only in proportion to its diameter or thickness. Now, capability of cooling, whether by radiation or convection, varies with the surface. Hence, a bar, say six times the thickness of a small bar or wire of round or square section, while it will have $6^2 = 36$ times the sectional area of the smaller, and so may carry about 36 times the current, has only six times the cooling surface. Hence, large bars as compared with small ones, besides being heated by the main current and by eddy currents, are still further handicapped, so to speak, by their greater difficulty in cooling. The eddy currents in wires, it may be mentioned, are so trifling as to be negligible. In ordinary drum or Gramme-wound dynamos, where the field is bored concentric with the axis of the armature, these Foucault currents arise principally, if not entirely, when the bars pass under the trailing horns of the pole-pieces, where the induction lines are particularly dense. By "trailing" horn is meant the last horn of a pole-piece which the bars leave or recede from as they revolve. The prevention of these internal eddy currents will form part of the subject of our next chapter.

CHAPTER IV.

HEAVY WINDING: PREVENTION OF FOUCAULT CURRENTS, AND VENTILATION.

THE methods for the prevention of Foucault currents may be divided under two heads. Under the first, the difficulty is met by removing the principal cause of the evil: under the second, the cause remains, but its effects are prevented from occurring by some counter-arrangement.

The plan adopted by Messrs. Mather and Platt comes under the first head. They avoid the difficulty by making the air space between the armature and the pole-pieces greater as it nears the horns either way, as shown in Fig. 8. Thus the principal cause of the heating is removed, inasmuch as the magnetic induction does not get so intense at the horns as it is wont to do when the air space is of even thickness.

But it is under the second head that we may look for the most variety. The eddy currents may be prevented by so making or arranging the bars that a current *cannot* circulate within them. One method, instead of making the bar of one solid piece, is to compound it of several insulated wires or strips, in such manner that there shall be no internal circuit open to the current. Thus, Messrs. Siemens Brothers make their conductor bars of stranded copper wire cable, each wire separately insulated by varnish, and the whole brought into a rectangular section by hydraulic pressure, or by drawing through a die, or otherwise. As the Foucault currents will only circulate in an unbroken circuit lying in a plane normal to the lines of force, as already explained, it will be seen that no such circuit is open in the cable arrangement: consequently, the currents are not set up.

Another method, somewhat similar, is to make the bar of insulated wires laid parallel, and soldered together at the ends so as to form a compound bar of rectangular section, to give the bar a half twist in the middle, and then to press or hammer the twisted portion in an iron mould, so as to bring it to the same section as, and alignment with, the untwisted portions of the length.

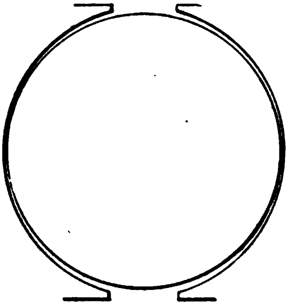


FIG. 8.

Yet another method is to make the bar of insulated copper strips or tape laid edgeways on the core in radial planes, and soldered together at the ends. The strips, thus laid, being in planes, for the most part approximately parallel to the lines of force they cut, will not, as we have already pointed out, be individually appreciably liable to eddy currents. But as they are in metallic connection at the ends, an internal circuit is open along the side strips and across both ends, which must be broken. Hence, this kind of bar also needs a half twist in the middle, and to be hammered in a mould, like the last. By means of the half twist, the current coursing along one side of the bar in each separate wire or strip is at the twist conducted to the other side, where it meets an opposing current, and so both are neutralised. It will, of course, be observed with regard to the strips, that if these be laid flat on the periphery of the drum, eddy currents could set up in each one separately.

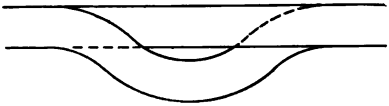


Fig. 9.

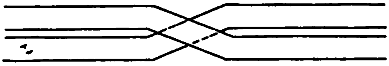


Fig. 10.

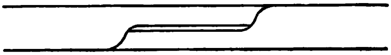


Fig. 11.

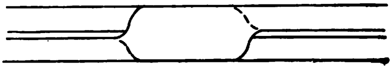


Fig. 12.

Further methods, still similar in principle, are some patented by Mr. R. E. Crompton. These are illustrated, Figs. 9 to 12. The conductor bar here is simply made double; but at the middle of its length each half is so bent that it continues on the centre line of, and in alignment with, the other half. A groove is turned in the core to receive the half loop. (Fig. 9.)

As will be observed, the circulation of a current within the double bar is stopped by the tendencies in each half being opposed at the middle crossing, similarly as in those already described.

Foucault currents may, however, be stopped by another method, included in one of Mr. James Swinburne's patents, by which any twist in compound bars is rendered unnecessary. This applies in cases where it is possible to connect up the component parts of two bars of a coil, separately, and in such a manner that the tendency to these currents in each bar shall oppose that in the other. This is achieved in the manner indicated diagrammatically in Fig. 13. The pulley end of the armature is here shown, and one coil, each bar of which is composed of four strips laid edgeways. The strips of the one bar must then be connected to those in the other bar, separately, in the manner represented. The coil is, in fact, split into so many parallel planes.

To understand this, we may imagine the coil to be revolving in the field in the direction indicated by the curved arrow. The upper pole-piece is north, and the lower south. The magnetic lines of force will be thus running from N to S, and will be most dense at the trailing horns, *a a*. As rotation takes place it will be seen that both bars are approaching dense portions of the field, and the lines of force are running through both bars in the same direction—that is, toward S. Hence, as viewed from some point in the same plane as the coil, on one side, but outside the armature, the eddy current would circulate in each bar in the same direction; or, as seen from S, in the same direction as the hands of a watch. Thus, at the sides *w* and *x* of the two bars, the current would approach; while at the sides *y* and *z* it would recede, as indicated by the small arrows. The opposition of the two tendencies is at once obvious. The union of the strips in each bar at the commutator is, of course, of no consequence.

The explanation can also be put in terms somewhat as follows:—Whereas the volts of *w z* may be greater or less than *y x*, the sum of the volts of *y z* will about equal the sum of the volts of *w x*. Hence no current will flow.

In all cases, it may be mentioned, the bars, whether solid or compound, may be wound with cotton or silk tape and varnish for insulation. Solid bars are sometimes left bare, insulated from one another by air gaps, and from the core by Willesden or Manilla paper, or other material, and varnish. They will, of course, be more liable to damage when left uncovered; but with compound bars the tape winding is, for the most part, necessary to maintain their shape. The varnish used is commonly shellac, though some makers use a speciality.

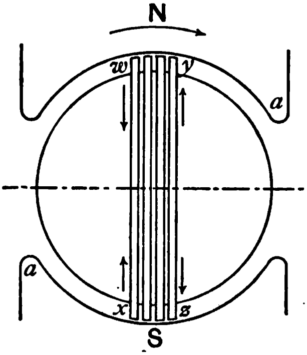


FIG. 13.

The heating of the bars should be still further obviated by efficient ventilation, a point we have already mentioned. The cores of large machines are usually made hollow. When revolving, the long lugs of the commutator, if there are any, act as centrifugal fan blades, and draw air through the hollow between the interior of the core and the spindle, and so assist to keep down the temperature. Some makers leave gaps in the core along its length, so that air from the interior may fly outwards, and help to keep cool, not only the core, but also the conductor bars on the periphery, and the pole-pieces. The bars will also draw air round after them, and so ventilate themselves. One of the advantages of the Hopkinson dynamo (Fig. 8) is thus here illustrated, since, owing to the fact that the horns stand away from the armature, air is more easily drawn down between it and the pole-pieces, and thus can be more effective in keeping the bars cool than when throttled and wire-drawn, as it were, by the closeness of the horns to the armature. The whole question of ventilation is not one to be passed over as inconsiderable. A phenomenon showing the effect of thorough ventilation may be observed when a dynamo stops after a run. The end winding, owing to its complete exposure and revolving in a thorough draught, may feel cool to the hand at first; but presently it will become warm, owing to the heat from the interior portions of the winding and armature creeping out. This shows at once how great a difference ventilation makes. It may be remarked that not only does heat tend to generate in the conductors, but also in the iron core and the pole-pieces, especially in the trailing horns of the latter. Hence, when it is further borne in mind that a high temperature reduces the conductivity of the copper, the desirability of good ventilation becomes still more obvious. In fact, other things being equal, a greater output is obtainable from a well-ventilated machine than from one not ventilated. When a machine is run very hot, energy is wasted in the dissipation of the heat, as already pointed out in an earlier passage. Some makers supply auxiliary fans, or air propellers, especially for the purpose of creating a draught through a machine as it runs. But, on the other hand, though thorough ventilation may keep the bars cool, there is yet, perhaps, some degree of falsity in the theory of this method of procedure. Heat is abstracted, and so energy lost, just as when the bars are allowed to heat—though it may be not so much owing to the lesser resistance of the cool bars—beside the loss of power involved in driving a fan when one is used. Only by good ventilation the heat is drawn off more quickly, and the bars are kept cool, and at their normal conductivity. Hence, as already intimated, the size and therefore the first cost of a well-ventilated machine for a given output should be less than for one not ventilated. In some machines ventilation is further assisted by the magnets being formed of bars, with interstices between them, through which air may pass in and out of the field. A practical limit, however, to heating is the ability of the various materials used for insulation to endure a high temperature without perishing or losing their insulating qualities. To this limit no doubt machines are sometimes run.

CHAPTER V.

HEAVY WINDING. PLATE END CONNECTION. EDISON.

We may now give our attention to some of the different methods in which heavy-current windings have been, and are, constructed, having special regard to the arrangement of the cross connections at the ends of the armature.

It will be noted that a bar being the reverse of flexible, it cannot be dealt with as a mere wire. To have to bend it would be a matter of considerable trouble. Hence special means have to be adopted at the drum ends. These consist principally, though not in all cases, of separate lengths of metal. These are used to form a connection between the ends of two opposing bars forming the two sides of a coil, and are united thereto by riveting, screwing, or soldering—the latter generally together with either of the two former. As we have already pointed out, in armatures for heavy currents there are generally only one, or, at the most, but two turns per section. If high volts are required, the machine must be made larger, or the field stronger, or the speed increased, or all three. Matters are thus much simplified. It is, of course, not mechanically impossible to have more turns per section. But the extra complications involved, combined with many other disadvantages, render the idea in ordinary cases inadmissible.

Among the earliest of these methods brought out is one patented by Edison. This is illustrated in Fig. 14, which shows an end view of an armature. The rectangular black dots *a a* are the parallel conductor bar ends. Each of these is let into and jointed to the periphery of a flat radial insulated metal plate, as shown. The radial plates of two bar ends desired to be connected up, such as *c* and *d*, are then united by a circular bar, as shown, jointed to each, but insulated from the other bars and plates. An electrical connection is thus carried round from one side to the other. It will be understood, in accordance with some of our preliminary remarks, that this sketch merely represents the principles of mechanical construction involved, and does not necessarily represent any one actual design. It is probable that the bars in Edison's early machines were connected up in the manner, though not in the order, here shown. The parallel conductors here are bare, and, it will be observed, are a long way apart. This method is practicable indeed for a winding of a few sections only. Though each end of the armature is thus connected up, yet at the commutator end, which is here given, alternate radial plates are projected further inwards than the remainder, as shown in solid black at *b b*. These projections

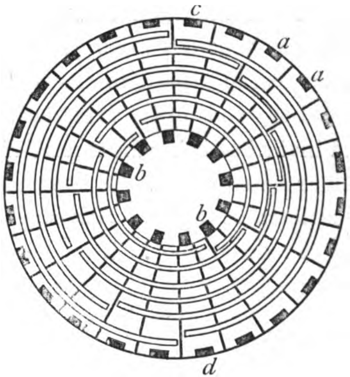


FIG. 14.

are each united to a commutator segment. Besides the drawback already intimated, this end winding has the further fault of not being symmetrical. Hence, a perfect balance and equality of resistance in the coils become often impossible. Some new arrangement thus becomes desirable.

In Figs. 15 and 16 we find the method adopted by Edison of placing insulated metal discs *a a* at each end of the core, and of the same number at each end as there are segments in the commutator, and of the same outside diameter as the core. A few of the parallel bars only

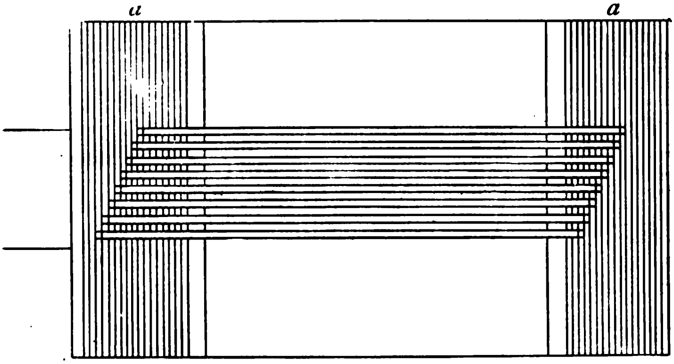


FIG. 15.

are shown. The two bars of a coil would thus at the pulley end be connected to the approximately opposite edges of the same insulated disc, while at the commutator end they would be jointed to separate discs. Fig. 16 shows one of these discs. A hole through the middle serves for the passage of the spindle and for ventilation, and a tongue *b* shown across it, cut through at one end, is bent outwards parallel with the spindle for connection with a commutator segment. The four smaller holes *c c* are for the passage of insulated screws running parallel with the spindle by which the whole set of discs at one end are bolted to the end plate of the core.

This arrangement has the advantage of being compact, and has all the joints on the outside and accessible. Hence any burnt or damaged bars can easily be renewed singly without disturbing the remainder. By making the discs rather stout in proportion to the current they have to carry, their resistance can be kept low, and the tendency to heat obviated, rendering their ventilation not so necessary. But they are liable to the disadvantage of having a maximum difference of potential between any two that are adjacent; and will thus require more care as to their insulation from each other. A drawback, moreover, to using round discs is that these have to be stamped or cut out from sheet metal, involving waste of metal, besides extra cost in labour and use of machinery. It is a point as to whether or not this cost is counterbalanced by subsequent facility of construction. It will be noted that the bars are straight, and have no bends; but in both designs, as shown in Figs. 14 and 15, it will be observed that these are solid, and are liable to heat with Foucault currents.

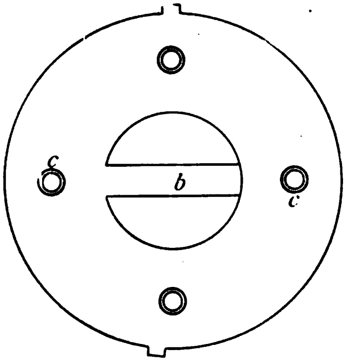


Fig. 16.

CHAPTER VI.

HEAVY WINDING. EVOLUTE END CONNECTIONS. CROMPTON AND SWINBURNE. ANDERSEN. HOPKINSON.

THE next example we may take is Messrs. Crompton and Swinburne's evolute end winding. This, as illustrated in Figs. 17 to 22, will be seen to differ entirely from Edison's. Fig. 17 represents an end view of the armature, Fig. 18 a longitudinal section, and Fig. 19 an outside elevation, all diagrammatic, and with a very open winding for the sake of clearness. It will be noted that alternate parallel bars run the full length of the armature, and are

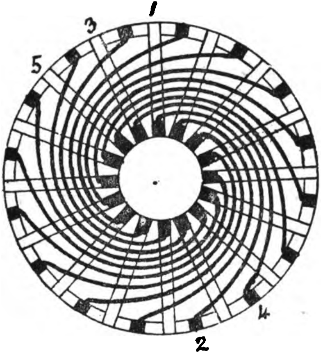


FIG. 17.—Crompton-Swinburne Winding. End View of Armature.

united to the commutator lugs at one end. The remaining bars are short, at least as to their straight portions, and we will for convenience call them so. A "long" bar and a "short" one opposite thus form the two sides of a coil. In Fig. 18 it will be seen that the short bars are cranked inwards towards the shaft, as shown at *a a*. At *b b* are sections through the evolute connections formed of thin pliable copper strips, indicated more clearly in the end view, Fig. 17. As may be seen, each of these, jointed at its interior end

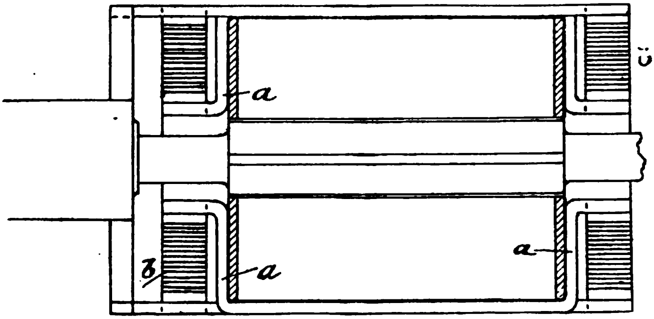


FIG. 18.—Crompton-Swinburne Winding. Longitudinal Section.

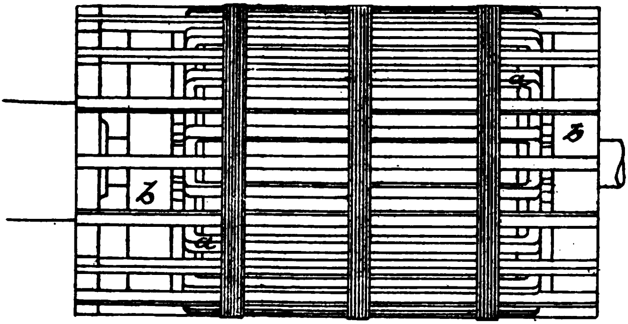


FIG. 19.—Crompton-Swinburne Winding. Outside Elevation.

to the crank of a short bar, is carried round in an evolute path till it reaches the desired long bar on the approximately opposite side, and there is jointed to it. It will be noted how the evolute connectors lie neatly within each other, though in practice they fit closely, separated only by mica or other insulation.

In the arrangement, however, as here shown, the cranked conductors, if burnt, cannot be removed without dismounting the whole winding, or a great part of it. Hence the modification shown (Fig. 20), where the crank is separately jointed to the turned-up end of the "short" bar, as indicated at *f*. By unsoldering these joints *f*, or the joints *g* between the "long" bars and the evolute connectors, any single parallel bar can be removed. Further, by withdrawing the spindle (which can be done if the core is carried on a spider, or otherwise self-contained apart from the spindle), the loose crank piece can be drawn in radially, its joint with the interior end of its connector unmade, when both can be removed singly. Thus any one, or a few sections, can be replaced without dismounting the remainder. The total number of joints is, however, increased. It will be noted that these bars are here all solid, and when single can only be used for small currents. For large currents the bars are made double, as illustrated, Figs. 9 to 12; or

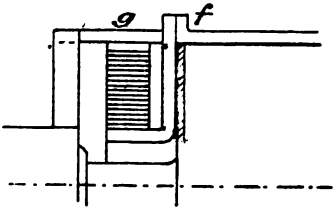


FIG. 20.—Crompton-Swinburne Winding.

else are compounded of twisted wires. In Fig. 21 is shown a modification to gain more room for the evolute connectors, the long bars being slightly cranked outwards.

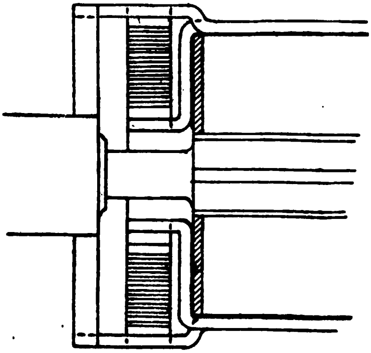


FIG. 21.—Crompton-Swinburne Winding.

Thus far we have dealt with but a single turn per section. In Fig. 22 is shown the arrangement for two turns per section. It will be seen that there are two parallel series of evolutes; also, the cranks are alternately long and short to suit. In this case the connectors may be narrower and

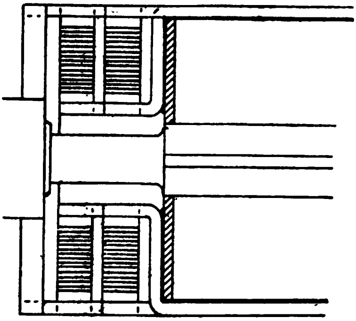


FIG. 22.—Crompton-Swinburne Winding.

thicker than in the former arrangement; thus in the total mass there will be more copper and less insulation than when the curved plates are thin; and so space is economised. The spindle within the core is either of triangular or square section, with slightly rounded angles. The core is carried tight on the angles, its interior bore being grooved to fit these, and ventilation is thus allowed for along the flats. Sometimes a spider is used to carry the core, instead of its being built on the shaft direct.

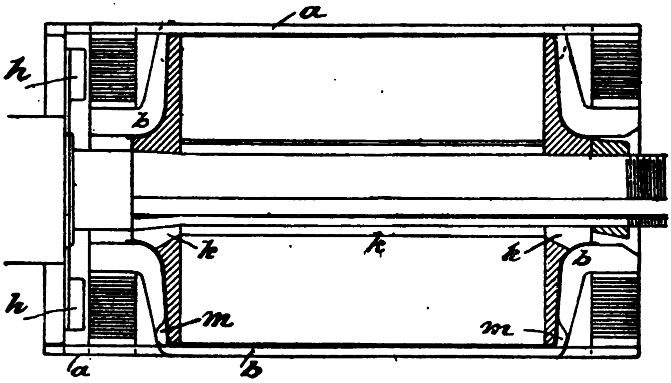
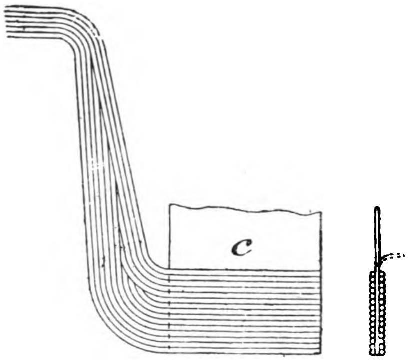


Fig. 23.—Andersen Winding. Longitudinal Section through Armature.

Further developments of this form of evolute end winding are to be found in the "Westminster" dynamos of Messrs. Latimer Clark, Muirhead and Co. This firm, under the supervision of their electrical manager, Mr. F. V. Andersen, have employed conductor-bars built up of either wire or tape, and sometimes both kinds on one armature. Fig. 23 shows a longitudinal section through an armature of this latter description. The long bars *a a* are of copper strips laid edgeways, and each strip insulated with varnish. The short bars *b b* are of wire laid parallel, each wire insulated with shellac varnish, and the whole group cranked at both ends. An end thus cranked is given to a larger scale in Figs. 24 and 25. The cranked end is splayed out, so that the wires embrace the inner end of an evolute strip *c*; and are the more carefully spread over the end of the strip, that the soldered joint may be as large as possible, and so offer a minimum resistance. A transverse section through the conductor bars on the periphery of the drum is given (Fig. 26), showing their compound formation alternately of copper strip and wire. Each bar is insulated with varnished tape. The layers *a a* are of Willesden or Manilla paper, varnished, and *b* is the usual exterior band of steel wire. The evolutes, duly insulated from each other, run from the inner cranks outwards to the long copper strip bars opposite, as in the case of the Crompton-Swinburne winding, shown in Fig. 17. The conductor bars are here jointed at both ends to other metal, and the several wires or strips in each are consequently in metallic contact at each end. They need to have a half-twist given them in the middle, in the manner already referred to when discussing the subject of



Figs. 24, 25.—Andersen Winding. Cranked Ends.

Foucault currents. In Fig. 23, *h h* are fan blades for drawing through the core by airways *k k*, of which there are three. In subsequent machines, however, these blades have been omitted, the suction caused by the commutator lugs being considered sufficient. The winding is held from slipping by a crown of teeth *m m* on each end plate, between which the cranks lie. A burnt section, however, cannot be taken out without dismounting at least half of the winding.

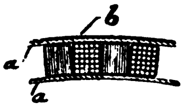


FIG. 26.—Andersen Winding. Transverse Section through the Conductor Bars on the Periphery of the Drum.

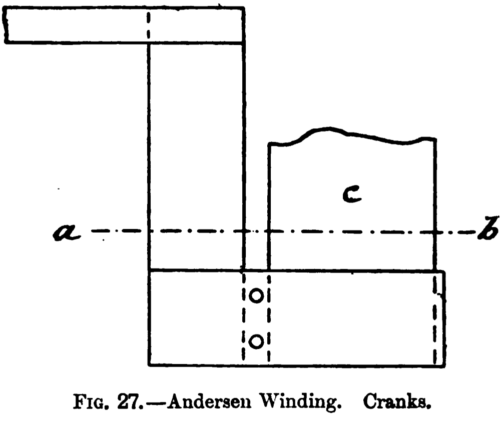


FIG. 27.—Andersen Winding. Cranks.

This firm has made machines with the conductors formed of copper tape only. As these are necessarily laid edgeways, and will not consequently easily bend, the cranks have to be formed of pieces soldered and rivetted together, in the manner shown in Figs. 27 and 28, the latter being a sectional plan on *a b* in the former to twice the scale. For the greater flexibility of the evolutes *c* these are here made of two thin strips of copper, instead of one, as is shown clearly in Fig. 28. Although this is of somewhat more simple construction than the wire-made cranked bars, inasmuch as these latter have to be carefully formed up in a mould, yet two extra joints are introduced.

It will be observed that these evolute windings so far represented have one common advantage. They are made entirely of rolled copper in one form or another. Hence all desired lengths need but to be cut off, with a minimum of waste, both in material, labour, and use of machinery.

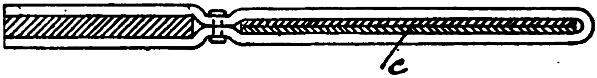


FIG. 28.—Andersen Winding. Sectional Plan on *a b* of Fig. 27.

On the other hand, comparatively speaking, the subsequent construction of the end winding is not exactly simple. In one method of procedure, the short bars have first to be made up separately, with cranked ends, and with the connectors, as yet straight, duly attached to each crank, and lying in the same plane with it. These, thus far individually complete, are then laid in position on the core, and temporarily bound on, with the connectors projecting radially all round. By roping and so forth, all the connectors at one end are now forced round in a combined mass, each one naturally assuming an evolute curve, until the outer end of each reaches the opposite side of the core end to that from whence it started, as shown in Fig. 16. Being held thus, and the connectors at the other end of the armature having been treated similarly, the long bars are finally added, and severally jointed up to their respective connectors. Hence, by the magnitude of the operation as a whole, it will be seen that the first-named advantage in the use of rolled copper is in some measure lost. One of the principal points, however, in this winding, as compared with Edison's discs, is, that there is a minimum electric pressure between the evolutes.

The evolute end windings we have thus far discussed, it may now be noted, have the peculiarity that each evolute from beginning to end is approximately half a circle. In another class of evolute winding, however, each evolute is approximately only a quarter circle, and the crank system is absent. This design was first brought out by Herr Hefner von Alteneck, and is that adopted by Drs. J. and E. Hopkinson in the manner represented in Figs. 29 to 32. Fig. 29 is a longitudinal section through an armature wound with one turn per section. Fig. 30 is an end view, but showing only a portion of the winding for the sake of clearness. The bars, it will be noted, are solid, the heating being obviated in the manner already described, by enlarging the air space under

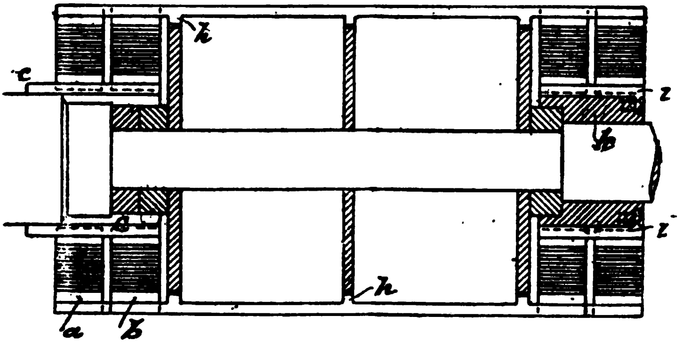


Fig. 29.—Hopkinson Winding. Longitudinal Section through an Armature.

the horns of the pole-pieces (Fig. 8). The parallel conductors in this case also are short and long. But instead of the short ones being cranked at their ends, they are jointed to evolute strips as well as the long bars. There are thus two series of evolute strips side by side, as shown at *a* and *b* in the illustrations. The evolutes in the one, however, run round in the opposite direction to those in the other, as shown in Fig. 30, and only cover an angle of approximately 90 degrees, instead of 180 degrees. On each commutator segment a bar *c* is screwed, which projects within the end winding in a direction parallel with the shaft. To this the interior end of

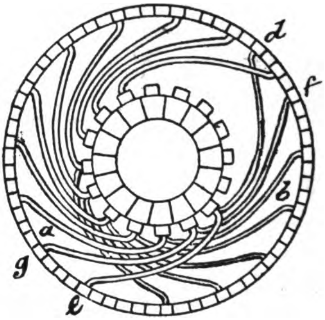


Fig. 30.—Hopkinson Winding. End View of Armature.

one connector in each series is screwed or otherwise jointed, thus connecting a long bar on the one side to a short one opposite, as, for instance, *d* and *e*, or *f* and *g*, as shown in Fig. 30. Figs. 31 and 32 show this arrangement duplicated for a winding of two turns per section, when there are four series of evolutes at each end.

The driving of the winding is effected by means of snugs formed in some or all of the bars themselves, which fit into recesses in the peripheries of the end plates and a middle disc, as shown at *h h* in Figs. 29 and 31. At the pulley end of the armature, there being no commutator bar for the strips to be fastened to, an annular block of insulating material *k* (Fig. 29) is run on the shaft, and on this bars *i i*, parallel with the shaft, are screwed for the purpose.

It will be noted that with this method of two or four series of evolutes, all the parallel bars are straight, without bends, and their joints being all external and accessible any can be removed separately. This latter advantage, however, does not appear to apply to the evolutes, should any of these require renewal. A minimum pressure exists between adjacent evolutes in any one series, as with the method of Messrs. Crompton and Swinburne. Likewise, also, the winding is

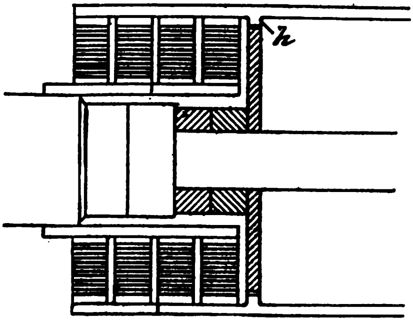


FIG. 31.—Hopkinson Winding. Two Turns per Section.

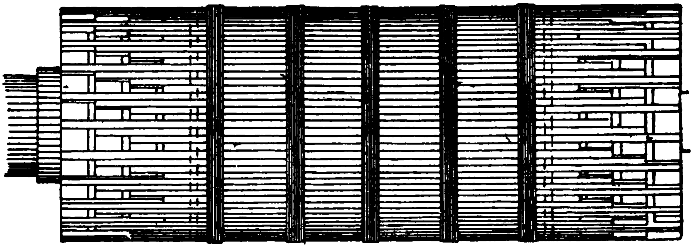


FIG. 32.—Hopkinson Winding. Two Turns per Section.

symmetrical, tending to a good balance, and the separate sections are all the same length round, and consequently of the same resistance. This winding is also constructed of rolled copper strips.

Instead of making these cross connectors in three pieces—that is, of two evolute strips united at their inner ends to one bar, as at *c* or *i*, Fig. 29—a simpler plan now in vogue is to make them each in one piece. This is illustrated above. A single strip of copper is first folded as shown in Fig. 33. One member *b* is then bent over into the dotted position *b′*, so that the whole appears in plan as represented in Fig 34. The two parts *a* and *b* will thus form the evolutes as depicted in Fig. 35; while the position *c* becomes radial.

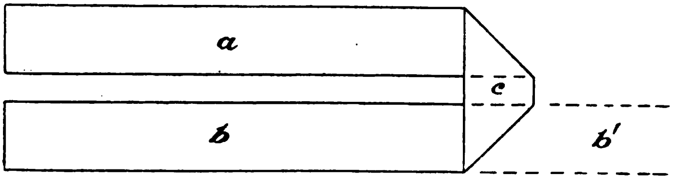


Fig. 33.

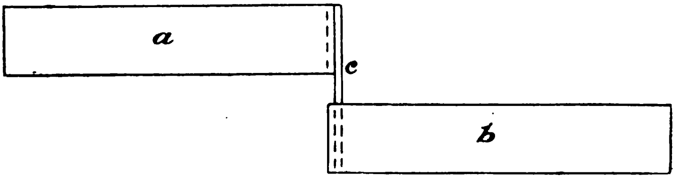


Fig. 34.

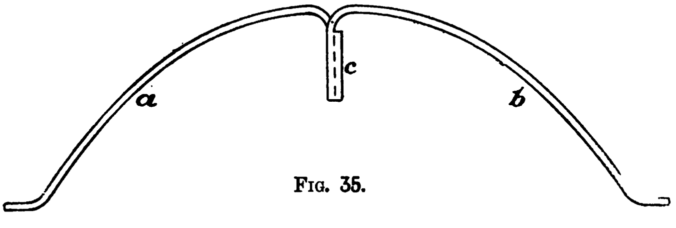


Fig. 35.

CHAPTER VII.

EVOLUTE WIRE-WINDING: EICKEMEYER.

We now come to another winding, the end connections of which are designed on the principle of a double series of evolutes, running in opposite directions, similarly to the last described. This is Eickemeyer's, of New York. Although like in principle to the Hefner von Alteneck method, it is in other respects altogether different. Each section of coil is composed of wires laid together, and contains no joint in it from one end at one commutator lug to the other end at the next lug. Each section, moreover, is entirely self-contained, and is formed to the right shape and curvature on a mould, or in part on a mould, before being put on to the armature. Thus the coils on any armature are exactly similar, and consequently interchangeable. Here, as with the Siemens' wire winding, a high-pressure small current can be obtained by making each section of one wire carried round several times; or the wires can be united in parallel, each section thus consisting of a group of wires carried round once. Or, again, a section composed in the aggregate of many turns of wire may be made up of a group of a few wires in parallel carried a few times round in series.

Figs. 36 to 39 are views of an armature fitted with a simple winding of two turns per section. Fig. 36 is an elevation

Fig. 37 is an end view with the commutator removed, leaving a section on line *p q* in Fig. 36. Fig. 38 is a plan of one coil, and Fig. 39 an isometric perspective view of the same. The portions lettered *b b* in Figs. 38 and 39 correspond to the outer parallel bars that lie on the periphery of the core on opposite sides of the armature. The parts *c c* (Fig. 38) lie across the ends, and correspond to the connectors. It will be observed in Fig. 39 that the downward angles *d d* are arranged to approach the shaft; while the swelling shoulders *e e e e* on either side will form the evolutes right and left, as shown in Fig. 37. As the current here is small, and the sections not numerous, the commutator is also small as compared with the armature. Hence, the connections *f* to the commutator are led off from one of the interior angles *d*. The pins *a a* in Figs. 36 and 37 are to drive the winding. The dotted lines *g g* in Fig. 36 represent the exterior binding wires. In Fig. 38

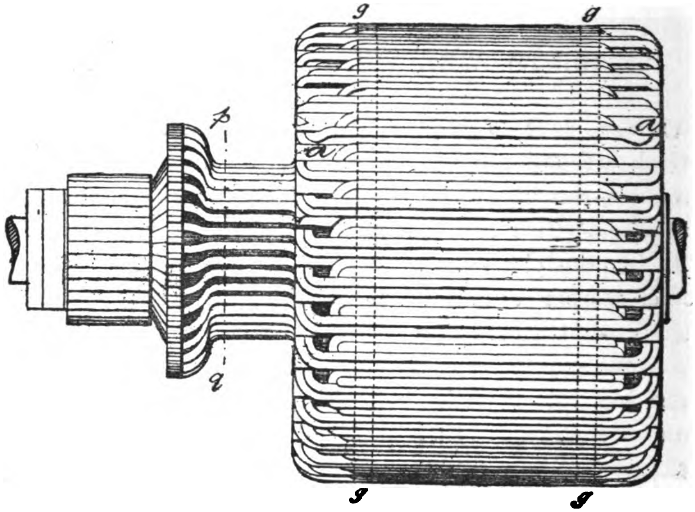


FIG. 36.—Eickemeyer Winding. Elevation of Armature.

it will be observed that one side, *b*, is longer than the other, thus, in fact, forming our "long" and "short" bars. This allows room for the two series of evolutes at each end of the armature; also, when putting the coils on the core, the small side of one coil can easily be passed within the large sides of other coils, and so allow of their being got into position.

In Figs. 40 and 41 an arrangement is shown of many turns per section for a small current of high voltage. Two coils are here represented, one of them being dotted in Fig. 40, but both shown in full in Fig. 41. It will be seen here clearly how the small side of the one fits within the large side of the other, leaving the clearance space *a a* between. The wires in the parallel bars are laid 4 × 2; while in the convolute portions they are all eight abreast, lying in curved planes parallel with the shaft. The "short" bars, it will be observed, are here intended to form a complete layer by themselves on the core

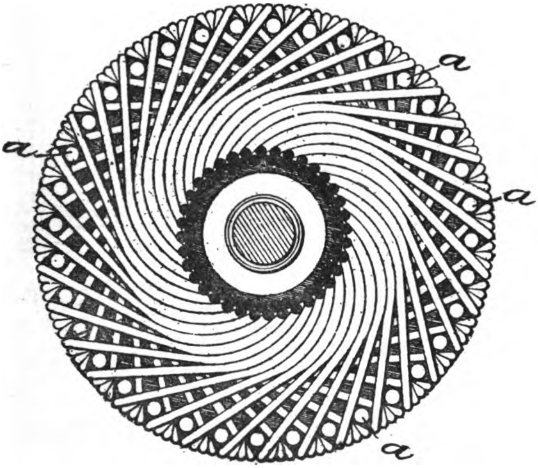


FIG. 37.—Eickemeyer Winding. End View of Armature with Commutator removed.

m m, while the "long" bars are arranged outside. The two sides of a coil thus come exactly opposite, instead of only nearly so. As the two layers will be exposed to a maximum

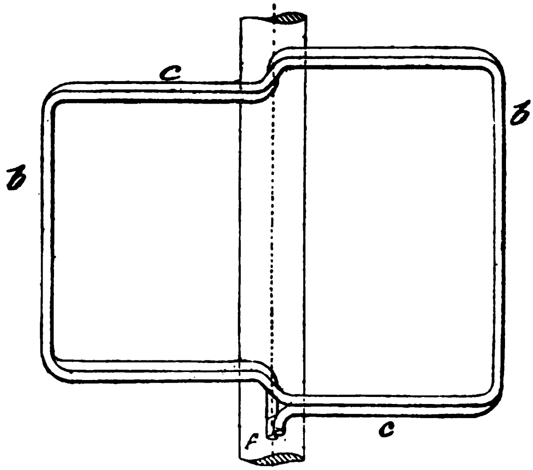


FIG. 38.—Eickemeyer Winding. Plan of a Single Coil.

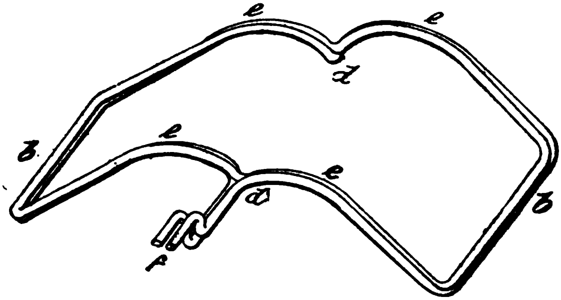


FIG. 39.—Eickemeyer Winding. Isometric Perspective View of a Single Coil.

difference of potential between them, they need to be well insulated from each other. This insulation, and the taping round the bars, are omitted in the sketches for the sake of clearness. In Fig. 41 the section through the bars of one coil is shown in solid black, *b b*, while through the other coil the wire sections are left clear circles, as shown *c c*. The connection to the commutator is led off from the middle at *f* (Fig. 40).

In Fig. 42 this same winding is shown, but with the wires in each coil all united in parallel for a large current. As the commutator will now need to be larger it will be more convenient to lead off the connections to it from the outside of the coils, as shown at *g*, rather than from the middle. This view, being a longitudinal section through the armature, also gives sections through the two series of evolutes at either end, showing clearly their mutual positions, and the air spaces *a a* between them effectually insulating one from the other. The semi-circular portions *d d* are the same as those similarly lettered in Figs. 40 and 41, where it will be seen that they lie in radial planes.

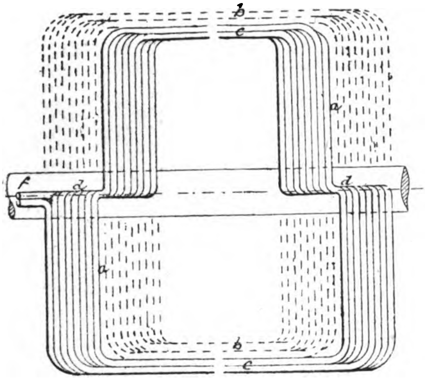


FIG. 40.—Eickemeyer Winding. Several Turns in Series per Section. Side View of Two Coils.

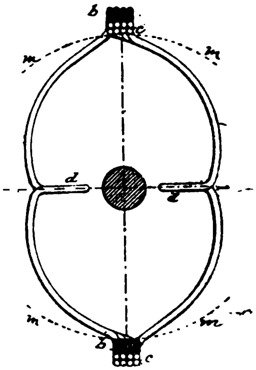


FIG. 41. — Eickemeyer Winding. Several Turns in Series per Section. End View of Two Coils.

A few words on this point of the air insulation. Our remarks will also apply to the Crompton and the Alteneck end-windings. This point, indeed, as has already been hinted at, constitutes one of the chief considerations of these special forms of end-winding. When adjacent coils are approximately in the plane of commutation, the "long" bar of one will be in connection with the commutator segment in contact with one brush, and the "long" bar of the other coil will similarly be connected to the other brush. Let the brushes be top and bottom, and the upper one positive. Using Fig. 42 for illustration, we shall now find that the bar *b* is at its highest pressure delivering current to the brush; while the bar *c*, being a side of the coil connected to the negative brush, is at a minimum pressure. Hence the two bars *b* and *c* are lying close together, with a maximum difference of pressure between them. On the other hand, as the volts only gradually rise in one long bar after another as they approach in order from the bottom to the top ~~on~~ both sides of the armature, it comes about that there is only a minimum pressure ever between adjacent long bars or adjacent short

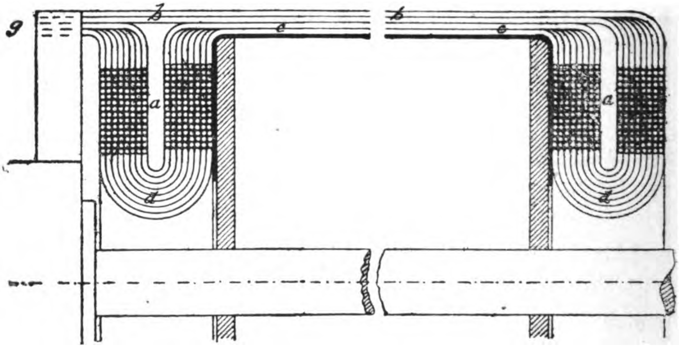


Fig. 42.—Eickemeyer Winding. Several Turns per Section, all in parallel. Longitudinal Section through the Armature.

bars. At the end of the armature, all the short bars are connected to the series of evolutes or radial cranks formed next the core ends; while all the long bars are united to the outer series. Hence there is only a minimum pressure between adjacent connectors in the same series; and any connectors proceeding from the ends of two adjacent long and short bars, with maximum volts between them, pass each into different series of evolutes, where they are effectually insulated by the air spaces *a a* between them. Thus it will be seen, that while a good amount of insulation may be put between the layers on the periphery, where it is required, without much affecting the total size; among the end connectors in either series, on the other hand, where a slight increase to the insulation between the strips would greatly affect the size of the whole mass, very little is needed. Hence, of the total mass of a series of evolutes, a much larger proportion can be allowed for the copper than might otherwise be the case.

This Eickemeyer winding, in common with the Alteneck and Crompton arrangements, will be observed to be symmetrical with the attendant advantages. One of the chief, however, among its many claims is the ease with which any damaged coil may be replaced, it being only necessary to undo the joints with the commutator, and remove the outside binding wires, to free the whole. It is economical also in total amount of copper used, and in labour of construction—after the coils are made, that is, as forming up the individual coils in the mould must doubtless take time. The absence of joints, however, especially in the case of large currents, remains one of its chief distinguishing characteristics.

As, both in connection with this latter and the previous windings we have described, we have alluded to the inside or outside union with the commutator, we may, perhaps, with advantage at this juncture also call attention incidentally to a result following on either of these two arrangements. In the Edison (Figs. 15 and 16) and the Hopkinson methods, as illustrated, and the Eickemeyer for low currents, this union is *interior*. In the Crompton and "Westminster" dynamos, and also the modified Eickemeyer for large currents, this union will be observed to be *exterior*. In the former case, and considering any one coupling, of whatever shape, that unites two opposite bar ends, the connection with the commutator is taken off from the *middle* of such coupling, halfway between the bar ends. In the latter, the connection is made at the *end* of a coupling, at its junction with a parallel bar. It will thus be seen that with the interior union, a plane through the axis of the commutator and one of its segments will be approximately at right angles to the planes of the coils to which such segment is connected. In the latter case, a plane through the commutator and such segments would be approximately coincident with the planes of its two coils—lying, in fact, between them. Now, in practice, and taking the case of a horizontal field, with pole pieces right and left, the polarity of the armature is brought by the much superior strength of the field to be nearly horizontal likewise: hence the plane of commutation comes about vertical. Thus, consequently, with exterior connections to the commutator, and assuming a horizontal field, the brushes will be top and bottom; while with interior connections, and a plane through the commutator axis and connected segment perpendicular to the plane of commutation, they will come at the sides of the commutator, right and left. It is to be noted, however, in the case of Edison's early end-winding (Fig. 14), that the connection, though *interior*, is yet taken off the *end* of a cross connector, the current running to or from the centre along a radial plate. Hence here the brushes would be top and bottom.

CHAPTER VIII.

HELICAL END WINDING: KAPP. CHORD WINDING: SWINBURNE.

A TYPE of drum armature winding, which, especially as regards the end connections, differs entirely from any of the foregoing, is the arrangement of Mr. Gisbert Kapp. Here the cross connections, instead of being laid as convolutes or discs, are arranged helically—in fact, like the threads of a many-threaded screw. In the case of copper-plate connectors, a common carpenter's wood screw, with thin, flat, and deep threads, will convey perhaps the best approximate idea.

Fig. 43 represents a part longitudinal section through an armature thus wound. The thickly placed vertical lines, O O, are sections through the series of helical connectors. These will be better understood from the developed plan shown in Fig. 44. The inner ends of the connectors, it will be observed, are jointed to the short parallel bars, as at *a a*; while the outer ends are jointed to the long parallel bars at *b b*—the unions being effected by means of tags T T, formed on the ends of the connectors for the purpose. A single helical connector is shown, Fig. 45. B B are the parallel conductors forming two sides of a coil, T T the tags, and *s* the commutator lug. The dotted lines S S′ show part of a true circular plane, thus making clearer by comparison the helical or spiral form of the connector.

Solid bar or wire connectors in the forms of insulated copper wire cable may also be used as shown in Fig. 46. A layer thus formed of bar or cable being of little radial thickness, other layers may be superimposed. As, however, the connectors in the outer layers must necessarily be longer than those in the inner layers, this latter method would appear not to have the symmetry of the helical plate arrangement.

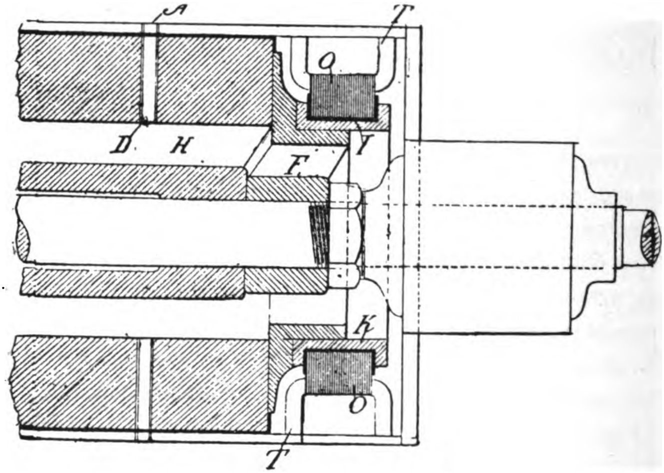


Fig. 43.—Kapp Winding. Longitudinal Section through Armature.

Returning to the plate connectors, each helix, it will be observed, goes round approximately half a circle (for a two-pole machine). All the helices, insulated from each other, are laid together in an annular frame I (Fig. 43) of wood, or other insulating material, and are held there by taping or otherwise; this frame is in turn held in a metal sleeve K, which is mounted on a shoulder of the end-plate F. Thus this end-winding has the peculiarity of being quite self-contained, and so can be made up separately, and not put on the armature till complete in itself. It will be observed that as the helices are attached at their ends to *alternate* parallel bars, between which there can only be a minimum pressure, there will likewise be only a minimum pressure between adjacent helices. Only a slight amount of insulation is consequently needed between them.

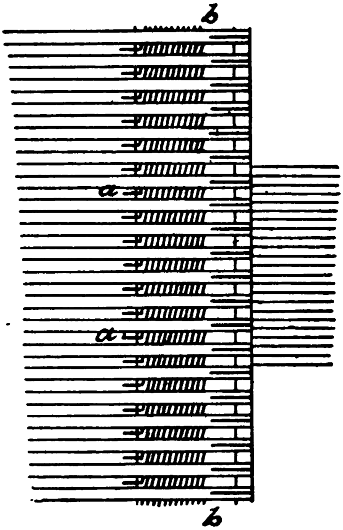


FIG. 44.—Kapp Winding. Plan of Helical End Connections.

An obvious advantage of this system over the convolute may be observed. If a large number of connectors are needed, it is not necessary to have two series, but merely to widen the one series in a direction parallel with the shaft. The "pitch" being thus increased, a greater number of any given thickness can be got in. As to ease of construction and replacement, it will be observed that all the joints are on the outside and accessible. In the core, at intervals, are placed metal discs with projecting horns A for driving the winding, and air spaces D at either side of these discs allow for ventilation. The core has a large central bore, admitting plenty of air, and is carried on a spider H as shown. It will be observed that, as with the Edison disc, these plate connectors require to be stamped out of sheet: hence the same remarks as to waste of material and cost of labour, &c., will apply, the question remaining as to whether or not this is made up for by subse-

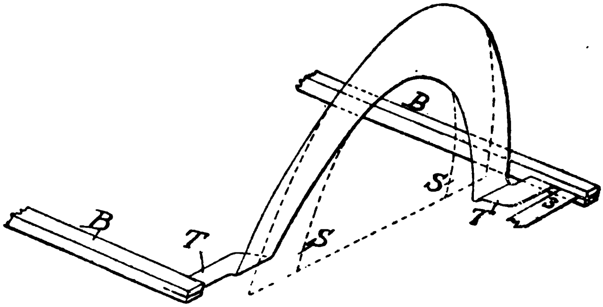


Fig. 45.—Kapp Winding. Single Helical Connector.

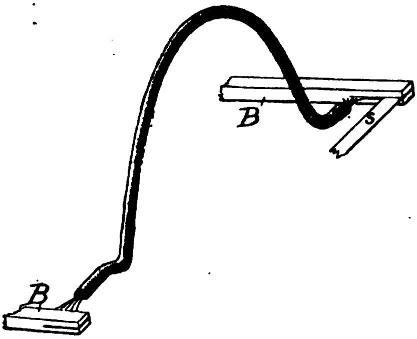


Fig. 46.—Kapp Winding. Single Helical Connector of Copper Wire Cable.

quent economy in labour of construction. This end-winding is very compact and symmetrical, with comparatively few joints, and these easily accessible, besides having the other advantages already mentioned, including free access for ventilation.

The next winding we come to is another of Mr. James Swinburne's. In this case the peculiarity exists that the coils, instead of being wound over diameters, are wound over chords of the circumference of the armature. An application of this principle to a wire-wound armature is shown in Fig. 47. It will here be seen that the end wrappings, lying in chords as at *a a* or *b b*, keep clear of the centre, and thus, especially when the chords subtend smaller angles at the centre than here represented, allow room for ventilation through the hollow of the core.

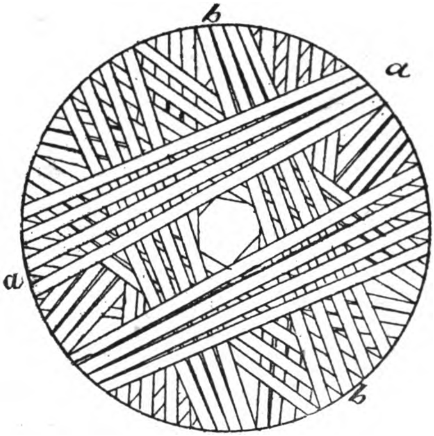


Fig. 47.—Swinburne's Chord Winding

For large low-pressure currents the method of coupling up across the ends is as shown Figs. 48 to 51. Curved stamped copper plates *a a* form the connectors. These are laid two in a plane normal to the axis of the armature, and with their edges butting as at *f* (Fig. 48). Connecting pieces *d d* are attached to the plates by means of which union with the bars *b b* is formed. The plates covering more than a third of a circle each, the space *c* may be kept clear for ventilation. Otherwise the plates may be laid slightly helically, and overlap

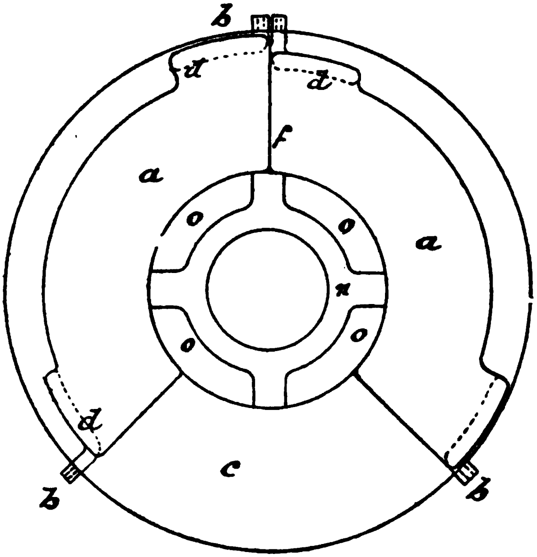


FIG. 48.—Swinburne's Chord Winding. End View of Armature, Two Connectors *in situ*.

one another. A spider *n* carries the core, passages *o o* being left for ventilation. Figs. 50 and 51 show separate views of one plate connector, with the addition of a tag *g* formed on the interior edge for interior union with the commutator, if such should be desired.

Foucault currents are dealt with by making each conductor bar of parallel strips or bars, and then connecting these up separately across the pulley end, as shown in Fig. 13 (page 35), it being borne in mind that in the case before us these connectors will be taken across a chord and not a diameter.

It would appear that in this end winding, as with Edison's discs, the close proximity of connector plates of maximum and minimum volts is not avoided. It will be observed, further, that the sum of the areas enclosed by the coils is not so great as would be the case were the winding diametrical. The plates require to be stamped. On the other hand, the construction is simple, and all the joints are outside and accessible. The connector plates are held in a mass to the end plates of the core by means of insulated screws, one of which is shown at *h*, Fig. 49. These screws of course also act as drivers, obviating the necessity of any special means for that purpose. Ventilation, as already intimated, is well provided for.

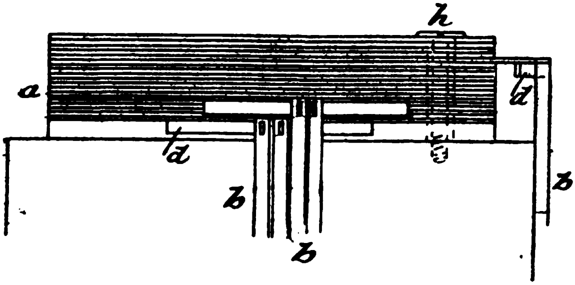


FIG. 49.—Swinburne's Chord Winding. Method of Connecting the Connector-plates to the End Plates of Armature Core by Insulating Screws *h*.

There are, however, some further points in connection with this winding which it may be of interest to consider. For the better elucidation of these, a diagrammatic representation of this system is appended in Fig. 52. The pulley end is here shown. The outer radial lines *y y* represent the commutator lugs at the further end extended on magnified diameters to make them visible. The curved dotted lines indicate the connections thereto. The lugs lettered B B are those of the segments on which the brushes rest, the left-hand one being the positive brush of the machine and the right-hand the negative, while the union with the commutator is supposed to be from the middle of a connector. Inspection will make it clear that the current flow is as shown by the small arrows.

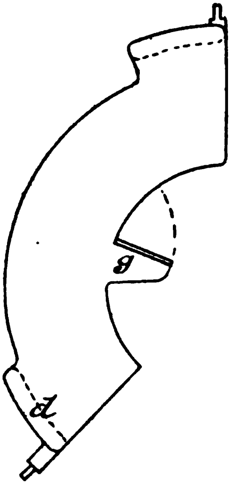


Fig. 50.
Swinburne's Chord Winding.

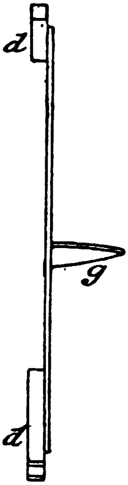


Fig. 51.
Separate Views of a Connector.

The pole pieces are also indicated, **N** and **S**. The small letters *n* and *s* show the armature polarity which each pair of parallel coils tends to produce. Thus the coils *a* and *b*, *c* and *d*, tend to produce between them a vertical polarity, each reinforcing the other, with a south pole above, and a north pole below. The pairs *e f* and *g h* tend to produce each an approximately horizontal polarity parallel with the field, but contrary to each other. These latter thus neutralise each other, with the result that the vertical polarity alone remains. In relation to the armature itself, this may be called its *primary* polarity. In relation to the field this is known as cross-magnetisation, or cross-induction, as it is at right angles to the field. Now

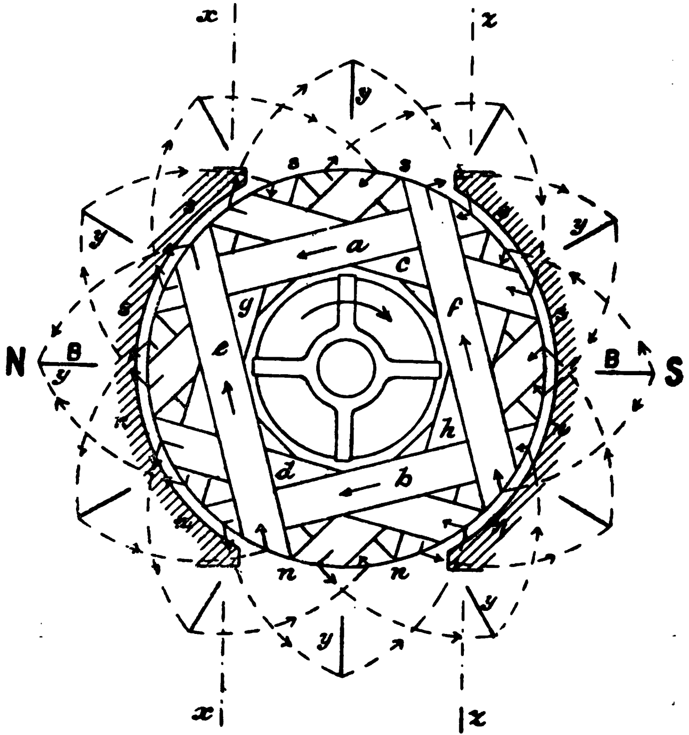


Fig. 52.—Swinburne's Chord Winding. Diagrammatic Sketch of System.

it will be observed that on the upper and lower sides of the armature, as sketched in Fig. 52, the current is running in opposite directions in adjacent parallel conductors; while at the sides next the pole-pieces the current runs the same way in all on one side. It is claimed in Mr. Swinburne's patent, that by virtue of this arrangement of current direction, the cross-magnetisation is reduced.

In ordinary-diametrical drum-winding, as explained in our first chapter, the coils adjacent on one side of the plane of commutation neutralise those on the other side. Thus, in Fig. 53, where *x x* is the plane of commutation, the coils *a a* neutralise the effect of the coils *b b*, in which the current is running in an opposite direction, as shown by small arrow-heads. On the other hand, the polarising effect of the horizontal coils *c c* is unopposed, and produces the vertical primary polarity of the armature coincident with the plane of commutation *x x*, which in relation to the field, as we have already mentioned, is known as cross-magnetisation.

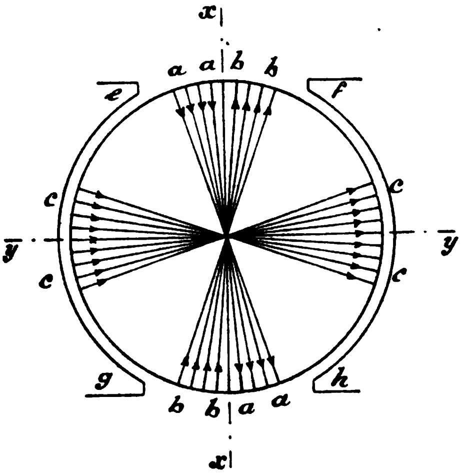


FIG. 53.—Ordinary Diametrical Drum Winding. Diagram of Current Flow.

Let us now suppose the brushes to require a lead. The plane of commutation becomes tilted as shown *x x* (Fig. 54). Now note the effect. The coils *a a a a* are brought normal to the field. Hence these will produce a polarity *parallel* to the field. In generating dynamos a north pole in the armature becomes opposed to the north pole-piece, and a south to the south, as indicated by small letters *n* and *s*, in direct opposition to the field. We thus find this polarity parallel with the field, termed, in the case of generators, the "back induction"; and its effect is to weaken the field. In the case of motors, wherein we may imagine the **N** and **S** pole-pieces to exchange

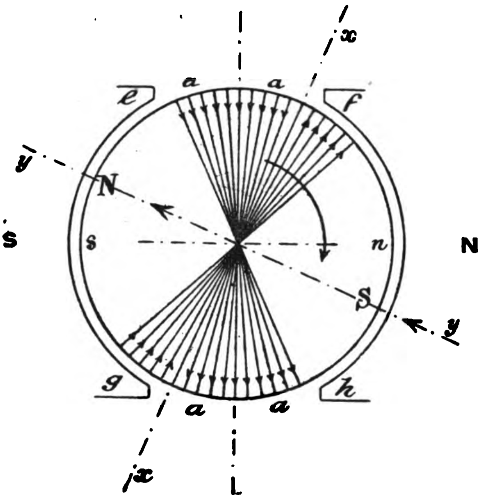


FIG. 54.—Same as Fig. 53. Brushes Shifted.

places, the reverse holds good, and this parallel induction reinforces the field: and the further phenomenon arises that, with an armature revolving between *non-magnetised* pole-pieces, and having a tilted plane of commutation, the south pole of this parallel induction will *induce* a north pole in the pole-piece opposed to it, and a south pole will similarly be *induced* in the other pole-piece. Thus with induced pole-pieces only, a motor can be run in a primarily non-magnetised field, though it may not pay to do so in practice. While a tilted plane of commutation is on this account not detrimental to a motor, but rather the contrary, it is detrimental in the case of a generating dynamo. Hence, to avoid this evil in the latter case, as has been already explained (*see* Chap. I.), the field is made so strong as to draw the primary cross polarity of the armature as nearly as possible parallel to itself. The ultimate effect is a compromise between the armature polarity and the field; and in proportion as the disparity is lessened, so great is the "distortion of the field." Thus, in Fig. 54, the lines of force of the field, instead of running straight across through the armature from **N** to **S**, will pass through along *y y* as a centre line of their course, the angle between *y y* and the horizontal being the measure of their distortion. The peculiarity will thus be noted that the primary polarity of the armature, or cross-magnetisation, is just exactly drawn down into the line *y y*, along which there is *no* primary polarity, as already pointed out, owing to the neutralisation of the coils *a a* and *b b*. The cross-induction thus diverted does not oppose the field. Assuming the plane of commutation to have been originally vertical, but the field becoming distorted by the armature, the brushes will require to be moved over till the plane of commutation is brought perpendicular to the new direction of the field, guidance as to when the correct position has been found being obtained by the absence of sparking at the commutator.

It may be further observed, referring to Figs. 53 and 54, that the whole of the armature above the line *y y* being north, and below, south, the horns *g* and *f* are opposed, and *e* and *h* reinforced, by the armature primary polarity. It thus comes about, that whether the plane of commutation be tilted or not, the lines of force gather thick at the horns *e* and *h*, which are the "trailing" horns, while at the other horns they become comparatively sparse. The Roman letters N and S indicate the ultimate polarity of the armature. In the case of a distorted field, Fig. 54, the main body of the lines of force running from the lower half of the **N** pole-piece and through the upper half of the **S** pole-piece, and these two halves thereby carrying the most lines of force, this further increases the accumulation at the horns *e* and *h*. The lines being drawn away from the horns *g* and *f*, these may become magnetised the wrong way if care be not taken.

Returning now to Mr. Swinburne's chord winding, and the claim for reduction of cross-magnetisation referred to, we find it difficult to see how this is made good. Referring to Fig. 52, we have found the cross-magnetisation to be due to the coils *a b c d*. The mixed bars above and below have but little effect in this direction, owing to the obliquity of the coils to which they belong. The whole of the upper half of the armature is of one pole, without primary opposition, and the lower half the other pole. The coils being on chords instead of diameters, it may be convenient to speak of two planes of commutation here, as represented by *x x* and *z z*. While these planes are vertical back induction cannot arise, as pointed out. But neither does it in diametrical winding. If the planes are tilted by a lead given the brushes, then back induction immediately sets up, as, for instance, the coils *e* and *f* becoming vertical will exercise influence opposing the field. In fact, with a lead to the brushes, a preponderance of the north primary polarity of the armature will be thrown against the north pole-piece, and of the south against the south pole-piece, and all the attendant consequences will follow as in the case of the diametrical winding. Hence it is not clear how this claim is substantiated; and this failing, it follows that this chord system of winding will not compare favourably with the diametrical winding, owing to the much smaller total area enclosed by the coils; unless, indeed, there be occult reasons in its favour, which have eluded investigation.

CHAPTER IX.

EXTERIOR END WINDING: CROMPTON AND KYLE. PARSONS. FRITSCHE.

A FEW more windings which we may touch on belong to an entirely distinct class, especially as regards their end connections. We refer to those in which the connections are made outside the circumference of the armature, instead of within.

The first of these we may consider is one patented by Messrs. Crompton and Kyle. This is based on the convolute principle, and consists of two series of convolutions running in opposite directions outside the armature ends. Figs. 55 and 56 illustrate this arrangement, though with only a portion of the connectors shown. On the outer circumference will be observed jointing plates *a a a* parallel with the shaft. From each of these there spring two evolutes *b b*, which proceed, one in each series of evolutes, to the opposing ends of a long and short bar respectively. One complete coupling *b a b* is thus shown apart in both views. Though cases may arise when this arrangement may be most suitable, yet in some respects it will not compare favourably with an inside end winding.

This form of winding plainly requires a longer coupling to unite the two ends of a diameter outside than inside the circumference. The joints, however, are all accessible after removing the commutator. But a disadvantage with this design results from the fact that an accumulation of material round the outer ends of the armature militates against the snugness of the machine as a whole. These remarks apply also to Figs. 20 and 21. It is desirable to keep the "magnetic circuit" through the magnets as short as possible, and the field coils need to be brought close up to the pole-pieces to obtain their fullest effect. It will, therefore, be observed that designers generally bring the field coils as near the armature as possible, and, in fact, in the case of vertical machines, rest them on the horns, as shown at *a a*, Fig. 57. Thus the lines of magnetic induction generated in the magnets within the coils can pervade the pole-pieces with the least possible loss of strength, and the total magnetic resistance is kept to a minimum. In the design of end winding before us, however, the connectors would come in contact with the field coils, so that these would have to go

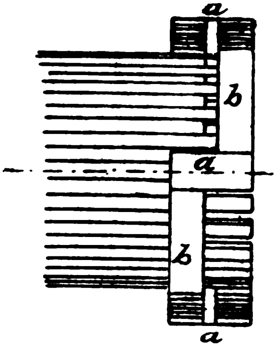


FIG. 55.—Crompton-Kyle Winding. Side View.

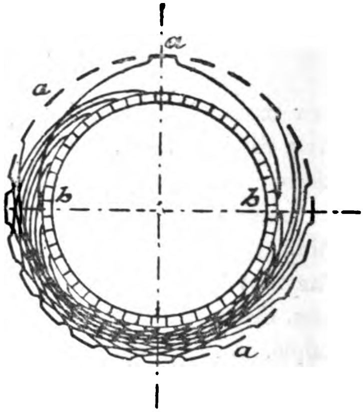


FIG. 56.—Crompton-Kyle Winding. End View.

further away from the armature, thus in some degree causing the advantage named to be sacrificed. This difficulty might, perhaps, be met by bending all the bars inward a little way toward the axis, as shown in Fig. 58. But bringing all the ends thus into a smaller circumference, unless the original spacing on the periphery of the core should be an open one, will tend to jamb them, and so necessitate their being formed

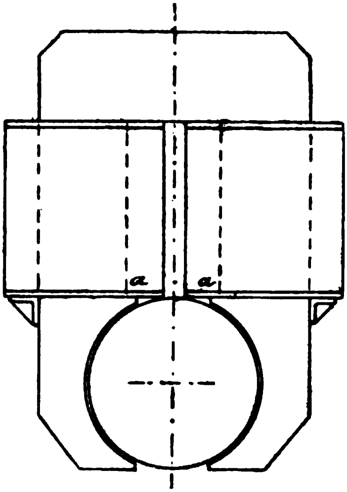


FIG. 57.

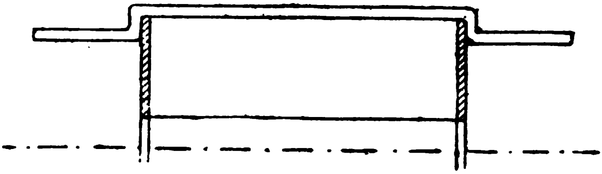


FIG. 58.

to a deeper and narrower section, thereby introducing complications.

The next arrangement of outside end winding to which we may refer is one patented by the Hon. Charles A. Parsons; though also independently invented by a young man of the name of White, in the employ of Messrs. Latimer Clark, Muirhead and Co. This is shown somewhat diagrammatically in Fig. 59, and is in principle somewhat related to Siemens's, Eickemeyer's, and Kapp's. With the two former it agrees in that each coil consists of one wire, or group of wires, without joint from end to end; with the latter, in that the helical principle is introduced at the armature ends. Thus a coil starting, say, from a commutator lug at *a*, pursues first a helical path through about a quarter circle to *b*, thence runs parallel to *c*, then down another helical path and approximate quarter circle to *d*, is here turned back on itself, and pursues another helical path to *e*, and so on until it ends at another lug at *g*.

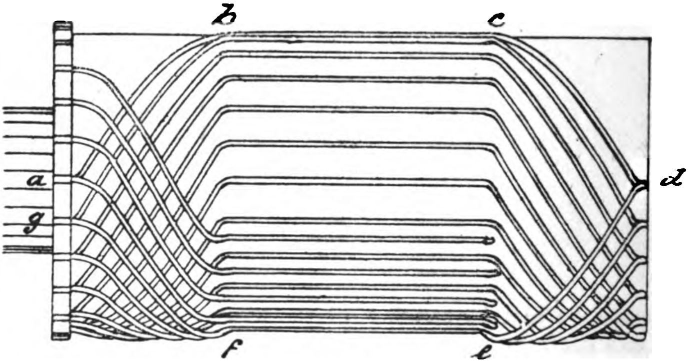


Fig. 59.—Diagram of Helical Outside-end Winding.

The Parsons winding is illustrated in Figs. 60 to 62, showing the two ends separately of the same armature.

There is here thus represented in practical form what is shown diagrammatically in Fig. 59. The parts lettered *z*, *w*, are sections through the inner and outer layers respectively of

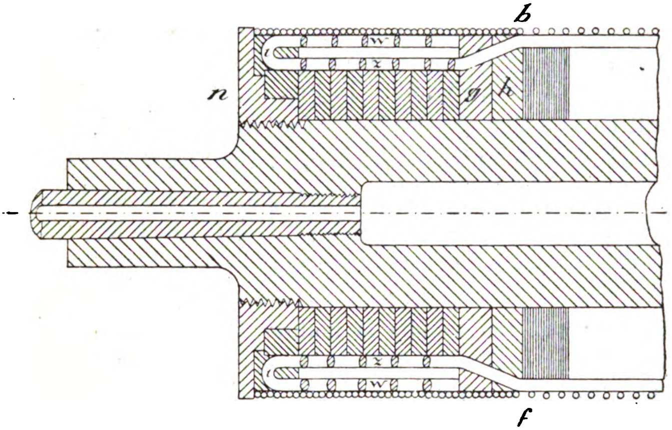


FIG. 60.—Parsons' Winding. Longitudinal Section through Engine end.

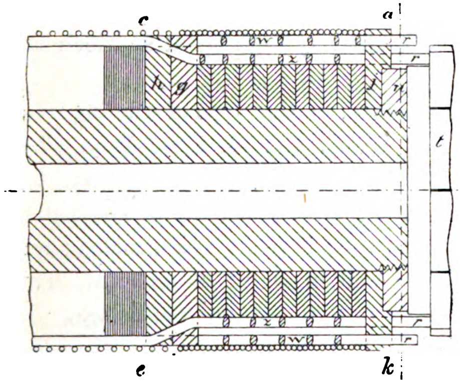


FIG. 61.
Parsons' Winding. Longitudinal Section through Commutator end.

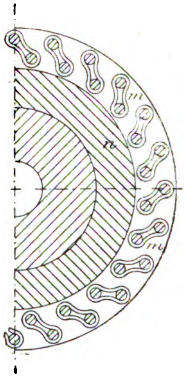


FIG. 62.
Section on *a k*.

the helical end winding: and it will be noted that at the ends the diameter of the armature is reduced, so that the exterior diameter of the winding is the same throughout. Beyond the limits of the iron core proper, *b f* and *c e*, the armature is non-magnetic, forming thus what may be termed a dummy core. The discs *g g*, *h h*, are of insulating material; and the smaller discs supporting the helical coils are of brass. At *i*, Fig. 60, it will be observed that the coils are turned back on themselves as at *d*, Fig. 59. In Fig. 61, on the other hand, it will be seen that the conductor bar ends, *r r*, pass through separate holes in an insulating disc, *j*; they are then coupled across by means of wire or copper strip and soldering, as shown at *m m*, Fig. 62. This latter method is that adopted in all cases when the conductors are too heavy to bend back as at *i*. The whole core is held on the spindle between two nuts, *n n*; and the spindle is hollow for the admission of fluid, such as cold water or oil, for the sake of cooling the parts. Two of the bars, *r r*, it will be observed, run out to the commutator, lettered *t*. On the core proper, between *b f* and *c e*, the bars lie in grooves, and are bound therein by a plentiful wrapping of steel wire, rendered especially necessary in this class of dynamo by the very high speed at which the armature rotates.

It will be observed, however, in this type of winding, that the helices being in two layers, and all those from what correspond to the "long" bars crossing those from the "short" bars, the evil of the close proximity of conductors of maximum and minimum volts is in no wise avoided; and the coils would need to be well insulated throughout. This form of winding is well exposed to exterior ventilation. To remove any burnt section, as in the case of the Eickemeyer arrangement, it would be necessary but to undo the connections with the commutator, and remove the exterior binding wires to loosen the whole. All its joints are accessible. But its requiring what we have termed "dummy" cores at the ends to support the helical portions of the winding, introduces so much waste weight. In consort, however, with the extremely high speed characteristic of the Parsons machine and steam-turbine, wherewith but a small diameter of armature is needed, this latter objection will not be of so much consequence as with a larger diameter. But this form of helical end winding makes a very long armature, entailing a long spindle and long machine altogether.

If, however, we take this winding, and imagine all the parallel portion included within the letters *b*, *c*, *e*, *f*, to be removed, so that *b f* coincides with *c e*, we shall then get approximately the last type of winding we propose to discuss, the Fritsche armature winding. The core of this armature is, in fact, wound helically; the whole winding comes within the field, and it may be said that there is *no* "end winding." The pole-pieces are placed diagonally in this machine, with the corners cut off, in the manner indicated by the dotted lines in Fig. 63. This, however, makes a bad field; for so large a proportion of the armature, as at *a a*, is uncovered by the pole-pieces; and the sectional area of the field, taken in a plane normal to its lines of force, is very much reduced compared to a field with the pole-pieces placed square in the usual manner. As regards facility for renewals, it is, of course, the same as the last described. On any armature, however, of a given diameter, it is not possible to put so

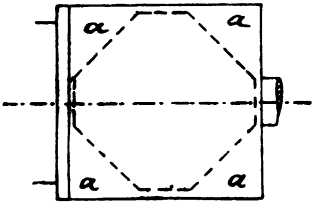


Fig. 63.—Fritsche Winding.

many bars of a given size when laid spirally as when laid in the ordinary manner parallel with the axis—comparing it, that is, with a parallel winding of two layers. Much care must obviously be involved in securing symmetry. An ulterior effect following on the diagonal arrangement of the pole-pieces to suit the helical winding is that, for any given output, the machine, as a whole, will need to be large and heavy as compared with others, and so will cost more. The coils, of course, have no joints, and, except those forming the inner layer, are well exposed to exterior ventilation. That the inner half should be without ventilation is a drawback. The commutator of this machine (of which a full account appeared in *The Electrician*, Vol. XXII., p. 655) is abnormally large, as indicated.

COMMUTATORS.

CHAPTER X.

COMMUTATORS.—INTRODUCTORY REMARKS.

THAT part of a dynamo which may be said to be next in importance to the armature and magnets is the commutator, or collector, as it is variously termed. For it is here that the current, after having been generated in the armature, is finally collected; and it is from and to this part that it is led away through the outer circuit of lamps and so forth, and brought back again for the renewal of lost energy or potential. On returning into the commutator at one side at minimum potential, the current courses through the armature, and is delivered again at the opposite side of the commutator *changed* to a current of maximum potential: hence the term "commutator," from the Latin *commuto*, to change, or alter entirely.

Our object is now to consider some of the various forms of commutator that have been brought out; and also some of the points that have to be kept in view when getting out the design for this portion of a dynamo, such as have led more or less to those differences of form to which we allude.

Without pretending that a commutator is to any very great extent intrinsically complicated, it yet would be a mistake to suppose that a design may be just "knocked off out of hand" without much thought. As great an amount of consideration within reason is required in designing a commutator as any other active part of a machine. For we shall find in the course of our investigation, that, as in all designing, from that of an ironclad downwards, there are conflicting requirements to be dealt with, both small and great. To these, therefore, and other collateral considerations, we purpose first to give our attention, before viewing any special examples in particular. Our remarks, moreover, must be premised by mentioning that we confine ourselves to commutators for close-coiled continuous-current machines, such as those having drum, Gramme, or flat-ring armatures.

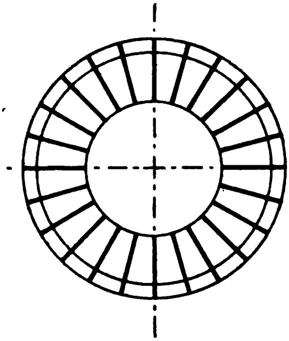


FIG. 64.

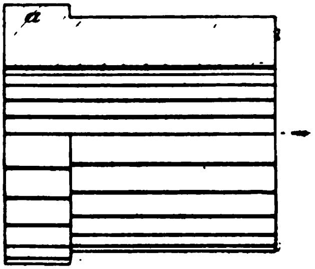


FIG. 65.

As is well known, the essential principle in the construction of a commutator is that of a series of segmental bars, held together on a substructure, insulated therefrom and from one another. This, omitting substructure, is illustrated in Figs. 64 and 65, the upper half of the latter being in section, so as to afford a full side view of one segment. The shoulder *a* represents the lug whereby connection is made with the armature winding, and through which the current runs either way between the winding and the segment. The thick black lines represent insulation.

Now, it is obviously the first consideration that each bar shall be large enough to carry the whole current without undue heating, and shall continue so after a reasonable amount of wear. It must be of sufficient thickness and depth, and have length enough to allow of a proper number of brushes to take the current off. But another consideration immediately follows, in respect of economy, inasmuch as the segments are usually of either copper, phosphor-bronze, or gun-metal, all of which are expensive materials. Hence, with regard to prime cost alone, it is not desirable to increase the dimensions overmuch either way. Again, as to the length, this dimension affects the length of the machine as a whole—in particular as to shaft and bedplate. This increases the total weight, and adds to the prime cost in respect of cast iron and steel. The diameter of the shaft would need increasing in due proportion. It also, however, means greater floor-space, or, on board ship, deck room. In the latter case especially, where space is limited, if one over-all dimension can be reduced without adding to another, there is an object in doing so. But this, it will be seen at once, is directly opposed to the already mentioned necessary condition, that there shall be a sufficient length of commutator for the brushes. We shall see later on, when dealing with particular designs, what methods have been adopted to meet this combination of requirements.

Now, the segments, besides being liable to wear from the constant rubbing of the brushes, are also liable to burn away from sparking between them and the brushes, especially if the sparking is such as flies from them to the brushes. This evil, however, is less liable to arise when the commutator is divided into many segments in proportion to the voltage than into a few. A commutator of many segments is thus for this reason desirable; and for the further reason that it would give a steadier current at any given speed than one with fewer parts. This question, however, is one with which the arrangement of the armature winding as a whole is concerned, inasmuch as there are the same number of segments in a commutator as there are sections in the winding. Now, with an armature wound in many sections for a high potential and a small current, the bars need not be of large section; yet they must be of appreciable size. But especially owing to the number of bars all requiring to be separated by insulation, this latter material, by its accumulation, forms a considerable factor in determining the diameter. Hence it comes about that the commutator will be of large diameter, sometimes nearly equalling that of the armature itself. But there being only a small current to be taken off by the brushes, the bars do not require to be long, and the commutator will be short in proportion to the diameter. It is obvious, however, on the other hand, that with any given speed, and greater consequent peripheral velocity, there will be more wear of both brushes and segments, and greater consumption of energy, due to the friction of the brushes, with a large diameter than with a small. But with a low potential, and large current, and small number of segments, the total amount of insulation between the bars will be reduced in proportion, while the length will need to be greater to accommodate those brushes. Hence the length of the commutator will be greater as compared with the diameter, and the latter considerably less than that of the armature.

The thickness of the brushes may, however, be a factor in this question. It is obvious, that with any given number of segments, the same peripheral brush contact surface subtending any given angle at the centre may be obtained by having either a long thin brush contact surface on a small diameter of commutator, or else a short broad one on a large diameter.

Though it is a common feature in small high-tension machines to see the commutator nearly as large in diameter as the armature, a peculiar instance where it is so in the case of a large machine is that of the Elwell-Parker * continuous-current transformer, or motor-generator. Here there are two commutators, one at each end. That receiving the high-tension current for the "motor" function of the machine is composed of a large number of small segments, and the total diameter is nearly equal to that of the armature; while at the same time the length is only a small fraction of the diameter. The other commutator, dealing with the low-potential large current, the outcome of the "generating" function of the machine, has many fewer segments, and is of smaller diameter; while the length is greater than that of the other commutator. Its length is about the same as its diameter, in fact, and a large brush contact surface results. The contact surface being proportional to the current, and not to the potential, much smaller brushes are sufficient on the high tension.

Returning once more to the subject of sparking, the principal bearing of this matter lies in the fact of its forming a reason for subdividing the commutator into as many parts as possible, as already intimated. The tendency to spark, and the secondary effect of the formation of "flats," are thus minimised. But, as will be seen, much subdivision increases the total amount of mica between the bars, and consequently the diameter also. Hence a compromise has to be effected, or at least too much subdivision avoided.

A peculiarity, however, in the wear of the segments, apart from their burning, is that, with wire brushes especially, annular grooves are apt to be cut round the commutator. This is mitigated by allowing the armature a slight end play in the bearings when possible. To equalise the wear also, it is usual to adjust the brushes, when there are more than one in a set, so that the gaps between those in one set do not come opposite

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* This machine is illustrated and described in *The Electrician*, Vol. XXVIII., p. 424.

the gaps in the other set. For the further reduction of wear and cutting it is commonly the practice to put a very little vaseline on the commutator. This is more necessary, however, when the bars are of soft copper or other metal. When of good hard metal, and with stencil-plate or gauze brushes, it appears to cause no detriment to run dry, without any lubrication.

Though under certain circumstances some oils may act as perfect insulators, better even than air, it is not desirable to let the oil from the bearings creep over or into the commutator. With large difference of potential between the segments and the parts of the machine at zero potential, a streak of oil between would carbonise; and carbon being a conductor, a short circuit would be set up, leading to leakage. To prevent this, among other reasons, a ridge is generally turned on the shaft, or on one of the nuts retaining the commutator, or elsewhere, from which the waste oil from the bearing is flung off, and is caught by an overhanging annular hood, or oil-catcher, projecting from the bearing, from which it is drained away.

As to the metal used for the segments, besides the gunmetal, phosphor-bronze, or copper, already mentioned, iron is sometimes used. The prevailing tendency is perhaps towards copper, though this somewhat depends on the form of the segment. Copper segments may either be cast, which can be done by alloying with a little silver—a method adopted by Messrs. Crompton and Co.—or else they can be rolled to the required segmental section and so be cut off in lengths. This metal is, of course, a better conductor than either phosphor-bronze, or gunmetal, or iron. The copper, when not cast, may be either hard rolled or else annealed. The former would be more durable; but the latter is better as regards conductivity. As, however, the ratio of the specific resistances of hard-drawn and annealed copper is given only as 1,652 to 1,615, this seems so slight in proportion that the question of durability would have more weight, and so the hard copper is preferable.

In the process of construction, these bars are filed, or otherwise worked up true, on their flat sides; then, with thin sheets of mica, usually about one thirty-second of an inch thick, and shellac or other varnish between them, they are all clamped together so as to form a hollow cylinder, as shown in Figs. 64 and 65. According to varying practice, the inside may or may not be bored. But while still clamped together they are put in the lathe, and the ends carefully turned to gauge. The substructure consists of a sleeve or bush, usually of gunmetal, though sometimes when large of cast iron. Over this the cylinder of segments is fitted with insulation between, and fastened on by a nut and washer. These latter are either wrought iron or gunmetal, or may be of steel. The whole now forming a compact structure by itself, the clamps are removed. Put in the lathe once more, the outside is carefully turned to asmooth bright surface. Though we shall deal with variations later on, commutators of this general type such as we are discussing have thus this characteristic in common, that when once built they are complete in themselves, and as such can be put on or off the shaft of the dynamo.

CHAPTER XI.

COMMUTATORS.—INSULATION.

Now, though the difference of potential between adjacent segments may be slight, yet this varies from a minimum at the plane of commutation to a maximum at the sides of the commutator, in a plane at right angles to the plane of commutation. For, as explained in our first chapter, assuming the plane of commutation to be vertical, and so the brushes at top and bottom, and the segments approximately in the same plane with the coils with which they are connected, those segments at the sides connected to coils lying horizontal are collecting potential at a maximum rate; while the vertical segments at the top and bottom are connected to coils which are generating practically no potential. The reasoning would be very similar in reference to Gramme-winding. But in consequence, the insulation between the segments must be sufficient to withstand this maximum difference of potential that occurs at the sides half way between the brushes. On the question of insulation, however, that between the bars and the substructure requires special attention; for there is the difference between the whole potential of the machine and the zero potential in the substructure to deal with. Here the insulation may be an eighth of an inch or more in thickness, and may consist of vulcanised fibre, mica, asbestos, or other material.

Between the segments, it may be mentioned, mica is specially suitable owing to its natural cleavage, which allows of its easily being split into the very thin sheets required. Moreover, it is hard and well adapted to resist the compressive strain brought upon it, and so, with the segments, help them to form a solid mass compact together.

Now, while on this subject of insulation, and inasmuch as the substance commonly known as "fibre" is so largely in use for this purpose, it may be of interest perhaps to add some remarks concerning it, for which, in the first instance, we are indebted to a somewhat complete *résumé* on the subject by manufacturers of this material.

Vulcanised fibre is produced by chemically treating specially prepared vegetable fibre, whereby the exterior portion of each separate filament becomes glutinous. While in this condition, the whole mass is consolidated under heavy pressure, and rendered practically homogeneous. The chemicals are then extracted, and the mass is manipulated, rolled, pressed, and cured by various methods. These operations being of an extremely delicate nature, liable to vary with different conditions of atmospheric moisture and temperature, it requires great skill, care, and experience, as in many other manufactures, to produce uniformly good results. The fibre is made in two qualities, "hard" and "flexible"; though for purposes of insulation the hard quality alone is applicable. A peculiarity is that this substance is produced only in sheet or tube forms. It will not mould; hence all objects to be made from it require to be cut out of either of these two forms, whichever may be the most suitable. The sheets, in size about 40in. by 60in., vary from $\frac{1}{50}$in. to $1\frac{1}{4}$in. thick, and are supplied in three colours, red, grey, and black; while the tubes, produced in lengths approaching two feet, have a thickness of shell not exceeding half an inch. It appears that these latter cannot be manufactured of less than $\frac{5}{16}$in. inside diameter, and the thickness, moreover, is proportioned somewhat to the diameter in the small sizes. Being rolled perfectly true and straight, with a good finish, they may be cut off into washers, or be used in lengths for enclosing and insulating bolts, and so forth. Though it has no grain, properly speaking, like wood, this material has none the less a species of cleavage parallel to the plane in which it is rolled. It may thus be split or cut comparatively easily in one direction, while it is hard to work in another.

As is well known, this material is strong, elastic and durable, even working well when used for the teeth of mortice wheels. This latter, however, depends on the teeth being lubricated with grease and blacklead, and *not with oil.* Fibre absorbs both oil and *water.* The former reduces its durability, while the latter would of course be fatal to its quality as an insulator. Such absorption causes it to swell, though it resumes its original size when dry again. Its specific gravity is about 1·3, and a cubic inch weighs about four-fifths of an ounce.

Originally imported from America, vulcanised fibre has been put on the market in England and the Continent as an insulator, and having some insulating qualities, and being easily worked, has been very generally adopted. In this connection, however, we may give a table of specific resistances, compiled from measurements taken by Profs. Ayrton and Perry, and which we quote from *Uppenborn's Electrical Calendar* :—

Vulcanised fibre	$1·2 \times 10^6$	megohms	(B.A.)	at	20°C.
Mica	84·0	„	„	„	20°C.
Gutta-percha	450·0	„	„	,	24°C.
Shellac	9000·0	„	„		28°C.
Hooper's vulcanised India-rubber	15000·0	,	„	„	24°C.
Ebonite	28000·0	„	„	„	46°C.
Paraffin	34000·0	„	„	„	46°C.
Glass	Still greater.				

From the above it will thus be noted that fibre ranks last as an insulator. Now, with the *India-Rubber and Gutta-*

Percha, &c., Trades' Journal (May 9, 1892), as our authority, we there find an account of some experiments made as to the specific resistance of vulcanised fibre by Mr. Eugen Müller, of Berne, the original of which appeared in the *Elektrotechnische Zeitschrift* (February 5, 1891).* The liability of fibre to absorb moisture has already been intimated. To how great a degree this liability extends, however, will be made clear from the following tabulated results of these experiments. It is to be observed that these were made under three different conditions.

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* We are indebted to the Editor of *The Electrician* for the following epitome of further correspondence on this subject:—

" Referring to this article, Mr. W. Courtenay, President of the Vulcanised Fibre Company, writes to point out the rapidity with which ebonite or vulcanite (even when it is of the best quality, which is seldom the case) deteriorates with age, whilst vulcanised fibre actually improves, and after eight or ten years has been found in a better state than when first put in. Moreover, ebonite or vulcanite is almost always adulterated, and in time becomes perfectly perished, and its only claim to being considered an insulator lies in the fact that it is waterproof. Mr. Courtenay entirely denies that vulcanised fibre contains either jute or oxide of iron, as asserted by Herr Müller. All Herr Müller's figures giving comparisons with paraffined wood are, says Mr. Courtenay, quite irrelevant. As everyone knows, paraffin is one of the best non-conductors, and wood being exceedingly porous, the tests given refer in reality to the paraffin, and not to the wood. It is not to be denied that ebonite and vulcanite when pure (which they seldom are) have a higher resistance against high potentials than fibre. Against this must be balanced the mechanical weakness to which they are liable. Herr Müller is aware that the hygroscopic properties can be entirely done away with by giving it a coating of shellac or other watertight varnish, whenever circumstances would otherwise allow it to absorb moisture. Mr. Courtenay states that it is by no means certain that Herr Müller had got hold of genuine specimens of fibre, as many imitations of the genuine article had been produced. In answer to this, Herr Müller, in a later issue of the *Elektrotechnische Zeitschrift*, states that the specimens of fibre tested were obtained from the sole agent of the Patent Vulcanised Fibre Company, Herr Wilfert, of Cologne. To this the latter replies that he has only supplied Herr Müller with a small sample of fibre, and that nearly two years ago. He also says that since the Vulcanised Fibre Company supply only one sort of fibre, whilst Herr Müller gives the results of tests on eight different varieties, there must be an error in supposing that the material experimented on was prepared by the Vulcanised Fibre Company."

Firstly, the fibre was previously thoroughly dried by being enclosed in an exsiccator for several weeks; secondly, experiments were made after its exposure for 24 hours only to the by no means damp atmosphere of the laboratory; and, thirdly, after exposure for several months. Results with walnut wood are also included. (Ω L = Legal megohms.)

Specific Resistance (at 15° C.) per Cubic Centimetre.

—	Dry.	Exposed 24 hours.	Exposed several months.
	A.	B.	C.
1. White vulcanised fibre	2,500 × 10^6 Ω L.	200 × 10^6 Ω L.	14 × 10^6 Ω L.
2. Different kind „	3,300 „	1,080 „	22 „
3. Light brown „	7,400 „	580 „	18 „
4. „ „	12,400 „	1,002 „	54 „
5. Red „	16,500 „	245 „	10 „
6. Black „	20,500 „	2,000 „	68 „
7. Red „	35,400 „	3,250 „	54 „
8. Brown „	48,500 „	3,800 „	26·3 „
9. Ordinary walnut wood	99,000 „	2,870 „	53 „
10. „ „	49,500 „	21,000 „	572 „
11. Paraffined „	∞	620,000 × 10^7 „	3,690 „
12. „ „	∞	185,000 × 10^6 „	11,080 „
13. „ „	∞	11,700 „	1,380 „
14. „ „	∞	∞	830 „

It will thus be seen that though fibre, when perfectly and absolutely dry, has decided insulating qualities, it rapidly deteriorates in this respect with exposure. The loss, in fact, is tremendous, even in the first 24 hours. But in the humid climate of England, wherewith by far the greater part of the year the atmosphere is damp, the first two columns in the table would with the better reason be considered as appertaining to a condition of things contrary to general experience. For safety, the last column (C) is the one on which calculations should be based. We here find the specific resistance ranging from

10×10^6 megohms (L) for one specimen of red fibre, to 68×10^6 megohms for a black specimen.

The means of the results, however, are given as follows :—

White vulcanised fibre	about	18×10^6 Ω L.
Brown " "	"	26×10^6 "
Red " "	"	32×10^6 "
Light brown "	"	36×10^6 "
Ordinary dry walnut wood	53 to	572×10^6 "
Paraffined " "	530 to	$11,000 \times 10^6$ "

In the first table we quoted it will have been noticed that the specific resistance of mica was given as 84×10^6 megohms (B.A.), at 20°C. This is considerably better than any results with exposed fibre, though by no means high as compared with the other insulating substances that follow it in the table.

It is obvious, however, that the whole question of insulation is bound up with the consideration of what is practicable and practical under any given conditions. Thus, in the case of commutators, with which we are more immediately concerned, mica, from its natural cleavage and hardness, is eminently suited for putting between the flat sides of the segments. For this purpose, therefore, it has been largely adopted. If we consider the various substances that are used generally for insulation, such as glass, porcelain, paraffin, ebonite, vulcanite, India-rubber, gutta-percha, besides mica, fibre, and so forth, we find none of the first-named are applicable for use in commutators—or, at least, are not used to our knowledge. India-rubber and gutta-percha are too soft; ebonite and vulcanite are too friable, and wanting in strength; glass and porcelain have a certain strength; and though one may be tempted to look at these, the practical difficulties of adapting them to a fit would be great, besides the question of their extreme brittleness, and liability to chip, crack, and break. In a commutator, the insulation has to form part of the general structure, and has to take strain in common with other material used. This at once limits the substances that are applicable. For the necessary strength, therefore, together with practicability of working and other qualifications, we find ourselves more or less confined to vulcanised fibre and mica, though asbestos and other materials have been adopted.

Now, the excessive hygroscopic properties of fibre, to which we have been drawing attention, and which interfere so largely with its quality as an insulator, cannot unfortunately with any success be diminished by paraffining. For on account of its very inferior porosity, the temperature of the paraffin has to be raised very high (about 180°C.) to make it penetrate; and at this heat the fibre decomposes with effervescence, becomes brittle, and is rendered perfectly useless. Its swelling with absorbed moisture, which may amount to $\frac{1}{32}$ in., or even more in an inch—and, contrariwise, its warping with heat—present considerable difficulties. For commutators—especially in the case, for instance, of motors worked out of doors—are exposed to every atmospheric change, on the one hand; while, on the other hand, they are liable to get warm from causes inherent to the machine. The futility, moreover, of any trust in a coating of varnish is apparent, in consideration of this not being able to prevent the effects of heat. In most cases, also, the fibre having been exposed to the air for some days at least, when being machined to shape, will have absorbed moisture before the application of the varnish, while any attempt to dry the fibre immediately before varnishing would probably cause some change of shape. It is thus for these various reasons that some firms are now abolishing vulcanised fibre altogether from their commutators, and are using mica throughout. We hence propose now to give our attention more particularly to this latter material, and its adaptability for use in commutators—for the cones especially.

Touching briefly on the sources whence mica comes, it may be stated that it is found and mined, among other places, in New Zealand, Australia, Canada, Bengal, Madras, and Ceylon. There are various kinds of mica, and the term is applied to a group of crystalline rocks having the peculiar laminated structure well known. While a small specimen may easily be sliced thin through the cleavage with a pocket-knife, on the edge it is about as hard as slate. It is found in slabs sometimes two or three inches in thickness. But it cannot be worked like slate, nor even as though it were hard wood or soft metal. When required of any particular shape, size, and thickness it is necessary to build it up to the approximate dimensions, of thin slices, separately worked, and all cemented together. The mass thus built may then be finished off by subsequent tooling. At the Electrical Exhibition at the Crystal Palace, in 1892, there were two exhibits of this substance, in the gallery, by Messrs. F. Wiggins and Sons, and Messrs. Wake and Sanders. In both of these there was a plentiful display of mica strips cut for use between the segments of a commutator. The former exhibitors, however, added two mica rings built up in the manner described, which were ready prepared for turning down into cones for commutators. These were to be observed in a case containing various very fine specimens of machined work, placed round the foot of a column of turned mica, which latter was doubtlessly unique in the Exhibition, as showing what can be produced with this material with proper knowledge and skill in its manipulation. Reverting to the rings, however, these are by no means wanting in strength. For, besides being hard on the edge, mica is also tough. A thin sheet will bend considerably before breaking. But unless built up in the manner described, it has no great strength to resist parting in the cleavage. Some firms build up their own rings, though, as intimated, they may also be had from the makers, leaving only the turning to accomplish.

Very heavy pressure is needed for making the rings—those at the Exhibition, for instance, though only about 8in. in diameter and $\frac{3}{4} \times \frac{3}{4}$in. in section, requiring no less a pressure than 175 tons. But in this manner cones may be obtained of sufficient strength, and as regards insulation and other qualities, considerably superior to vulcanised fibre.

CHAPTER XII.

COMMUTATORS.—METHODS OF CONSTRUCTION.

Having thus briefly reviewed some of the different points that occur in connection with the design and construction of commutators generally, we may proceed now to the consideration of definite examples. In so doing, it may be helpful to adopt some kind of classification. Thus a general division may be drawn between those designed to give the greatest depth of wear for the brushes, and those in which shortness of length has been made a special object. Figs. 66 to 69 herewith illustrate designs of the first class, each showing a longitudinal section through the upper half of a commutator only, similar to the upper half of Fig. 65, as with other figures that follow. Figs. 66 and 67 show two forms of commutator as made by Messrs. Crompton and Co., Limited; Fig. 68 is that of Mordey's "Victoria" dynamo; and Fig. 69 shows the commutator of the "Helvetia" dynamo, constructed by Messrs. Alioth and Co., of Basle. It should be mentioned, however, in reference to these and succeeding figures that they are not scale drawings from specific examples; and though suited for the purpose of this work, no guarantee is intended that they all illustrate present day practice. Few parts of a dynamo probably are more affected by change than the commutator;

and it is our purpose to discuss the reasons that lead to such changes, rather than merely to illustrate ultimate results.

Now, the leading principle of these four examples is that of endurance. For there is no limit to the depth to which

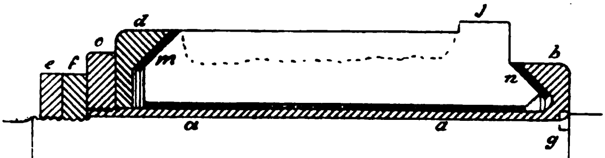


Fig. 66.—Crompton.

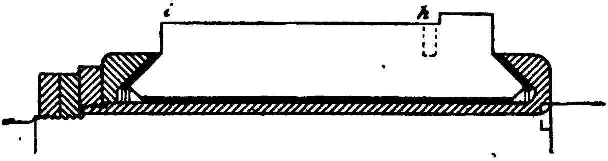


Fig. 67.—Crompton.

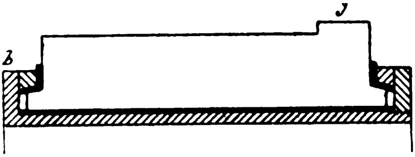


Fig. 68.—Mordey's "Victoria."

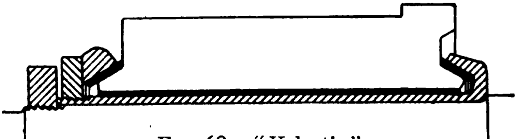


Fig. 69.—"Helvetia."

the bars may be worn down. They may, in fact, be worn right through—an occurrence which is not unknown; though allowing a commutator to run so long instead of renewing at an earlier period is perhaps scarcely commendable. This is, however, a leading point in these designs. Regarding them more closely, we note that they are all mounted on a sleeve or bush *a a*, which in Figs. 66, 67 and 69 has a mushroom head, *b*. In Fig. 68 the head is flat, and is placed at the contrary end to that where the shoulder *j* for the lugs occurs, as compared with the other figures. The segments are held on by a nut and washer *c d*: and in Figs. 66 and 67, the whole commutator is held on the shaft by a nut and lock-nut *f e*. In Fig. 69 only one nut is used for this latter purpose. The solid black represents insulation.

Having regard now more particularly to Fig. 66, it will be noted that the washer *d* is of the same diameter as that of the combined segments. Thus it differs from the other designs in that these latter have a clear shoulder at the left end, as shown lettered *i* in Fig. 67. It may perhaps be said, without its being stated as a set rule, that Fig. 66 is more especially suited for small sizes. For this, referring to the nuts and washers, would be on the general principle that parts should never be too small absolutely. On a large scale certain parts might be minute in proportion to the whole, but not so absolutely—or in other words—to the size of a man. The same parts on a smaller scale would need to be of increased size in proportion to the whole, to avoid being too small absolutely. Beyond this consideration, however, a clear shoulder as at *i* allows of an unhampered peripheral surface for wearing down. A groove turned at the other end as shown dotted at *h*, Fig. 67, leaves a surface clear at both ends. In Fig. 66 the dotted line shows how the wear is confined and hampered at both ends, and illustrates the difficulty, if not impossibility, of keeping the wear even all along, so as to avoid sparking. The surface *i h* in Fig. 67 has not these difficulties. In a patent for this groove *h* taken out by Mr. J. W. Easton, of New York, it is recommended that it should be kept filled with some easily removed insulating material, to prevent its filling with metal dust from the wear of segments and brushes, which might otherwise cause short circuits between the bars. Though familiar with the idea of the annular slot some time before the date of this patent, we are not aware to what extent, and with what success, this method has been adopted in practice.

As to the washers and heads, it will be noted that in Fig. 68 there is one of the former at each end, on account of the flat head. A point, however, to which attention may be drawn is the angle with the axis under the head and washer, as at *m* and *n*, Fig. 66, assumed in different designs. This, as will be seen further in subsequent sketches, varies from about 60° and 50°, to 45°, 30°, and even less. A great difference thus exists. The principal point to be attained, however, beyond holding the segments securely against the centrifugal force tending to make them fly off, is to hold them so firmly together, considering the large number of parts forming the whole, that they shall not easily be put out of truth, after leaving the lathe, by any accidental blow or jar. With the larger angle, the best effect, of course, is to hold the segments tightly between the washer and head; while the smaller angles have a best effect in holding the segments in toward the axis. It has to be considered, however, that insulating materials have not the same density and solidity as metals. They, moreover, vary in nature, and, as has already been pointed out, fibre is apt to absorb moisture and swell thereby, and to shrink again when dry and hot. Now, this shrinkage would naturally have more effect in loosening the bars diametrically with the large angles than the small. Thus a small angle with the axis might seem the best with fibre. But a substance less liable to shrink, such as mica, may be preferable for large angles. Conversely also, in consideration of its laminæ being in planes normal to the axis of the shaft, a large angle would be better for the mica, when so used. With a small angle, and assuming the possibility of there being any *give* in the insulation between the bars, and assuming further that these are tightly fitted on the cylindrical body of the sleeve, with hard insulation between, then on the nut being tightened up, and the slope of the washer having its best effect diametrically inwards, there would be a tendency for the ends of the bars within the washer to become jambed against the sleeve, the slope of the washer in a manner acting as a wedge. The result of this would thus be, that the segments dragging on the sleeve would not be driven home so tight under the head as under the washer. In Fig. 68, where the angle is very small indeed, any possibility of this eventuality is met by the fact that the washers at each end lie flat against the nut and head respectively, and also against the bar ends; and thus the bars are driven directly by the nut. There does not seem much allowance here, however, for any give of the insulation enclosed between the washer and the projecting heels or snugs of the segments. A practical point is to allow a thickness of sleeve where the nut rides for a sufficiently large thread; and a length parallel with the axis, such that the nut may not be too thin: thus, tight screwing up may be effected without the thread stripping, or the nut bursting, which is of course a matter of primary importance in securing the solidity of the whole mass. This nut, it should be mentioned, requires to be locked to prevent possible slacking back. One method is to put radial screws through it, generally three, with their points taking into the sleeve. Another method is to put one or more screws parallel with the shaft through the nut, with their points taking into the washer, as shown in Fig. 77.

But now we may turn our attention to commutators of the second kind in our classification. We find these exemplified in Figs. 70 to 73. Of these, Fig. 70 is a Kennedy design; Fig. 71 an example from a " Westminster " dynamo by Messrs. Latimer Clark, Muirhead, and Co.; Fig. 72 a Gülcher; and Fig. 73 an early type of Kapp commutator. Here, as was intimated, a special object has been to secure a short total length in proportion to the length of brush contact surface. The difference between these and the first four is at once apparent, in that they are undercut at the ends, and the washer and mushroom head more or less let into the ends of the segments. This is especially the case with Figs. 70 and 71; while with the former in particular the total length scarcely exceeds that of the segments. A further difference, how-

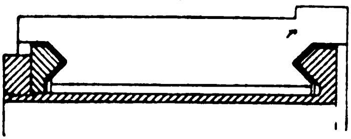


Fig. 70.—Kennedy.

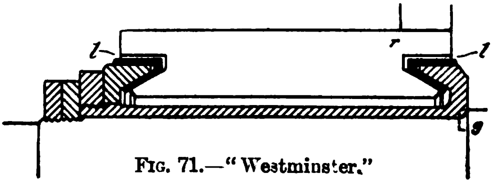


Fig. 71.—"Westminster."

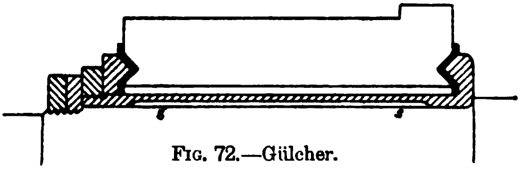


Fig. 72.—Gülcher.

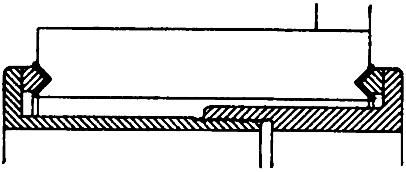


Fig. 73.—Kapp.

ever, will be seen, in that while the segments of the first four were all bedded on the sleeve with insulation between, in these latter there is no insulating material here, an air space between being left instead. Moreover, whereas the washers and heads of the former had only one slope, tending to force the segments inwards, in these latter, excluding Fig. 71, there are two slopes. Thus the effect of tightening the nut is to maintain the segments at a constant diameter or pitch, instead of only forcing them inwards. This forms an essential difference in construction. The angles of the reverse slopes are 45° with the axis of the shaft. Now in Fig. 71 we find this peculiarity that air spaces are left, lettered *l l*, between the inner side of the undercut and the outer periphery of the insulation; while at the same time there is no bedding on the sleeve, and the washer and head have only one slope. Thus the bars are all simply pressed inwards by tightening the nut, and held together like the voussoirs of a circular arch or culvert; the case would be analogous in Figs. 66 to 69 were the interior insulation round the sleeve omitted or but loosely fitted or packed in. If, however, returning to Fig. 71, the spaces *l l* were filled up solid, then the segments here also would be maintained at one set diameter or pitch, as in the case of Figs. 70, 72, and 73. Assuming, however, the single slope, without there being any direct support for the bars radially from the centre, then, especially when the commutator is divided into a large number of parts, the taper of each segment on its cross section is so slight, that an accidental blow on the outside, on any one or two of them, might drive them in, in spite of the tightness of the nut; thus the whole would be put out of truth, necessitating a return to the lathe. Hence a direct support both inwards and outwards would appear preferable, either by means of the single slope under the head and washer, and bedding on the sleeve, or else by double slopes on washer and head, as in Figs. 70, 72, and 73.

In these four designs, Figs. 70 and 71 especially, it will be observed that the brushes cannot wear right through, as they were open to do in Figs. 66 to 69, for they would reach the washer and insulating ring before doing so. They all have a clear shoulder, as at *i*, Fig. 67. It might appear in reference to Figs. 70 and 71 that on much wear taking place the sections of the segments at *r* would become so reduced as to choke the current flowing to and from the lug. But as so little wear is allowed at all, renewals would be needed before much trouble in this direction could arise, at least, in the case of Fig. 70. Excessive wear may, of course, lead to difficulties here, as elsewhere. In the other designs the undercut is not nearly so great. It may be noted that there was a slight undercut at the lug end in Fig. 69.

Regarding the matter now, however, from the point of view of prime cost, we find these latter four examples compare favourably with the former. Thus a slight gain accrues at once from the shorter sleeves. But from the fact that there is no insulation between the bars and the sleeve, and provided the air space thus left is not less than (say) $\frac{3}{16}$in., there is no necessity either to bore the interior of the segments or to turn the outer cylindrical surface of the sleeve; and so machining is saved. In Fig. 72 a further saving in this same direction is effected by chambering the interior cylindrical surface, lettered *s s*, thus leaving only the ends to bore smooth to fit the shaft, while the chambered portion need have only a roughing cut taken off it, if any. Moreover, as the length of the segments themselves in the latter four does not exceed what is required for the brushes and lugs, whereas in all the other designs we illustrate there are projections at both ends beyond these limits, metal is saved in this respect. Economy is also effected, of course, in insulation.

A distinctive feature in Fig. 73 is that nuts are eschewed, and two sleeves are adopted, the one screwing into the other, as shown. As in Fig. 68, however, it has two washers, one at each end, and both from the same pattern. We may note a further characteristic which these hold in common with the washers in Figs. 68 and 69. This is that they are not centred on the sleeve, excepting in so far as in Figs. 68 and 69 the washers there force the segments on to the interior insulation, and so become centred thereon themselves. In the other designs before us the washers are bored to fit the sleeve, and so are centred on it; and they are thus the better adapted to assist in maintaining the truth of the commutator. But in Fig. 73 they are not centred on anything whatever, and entire dependence for maintenance of truth is apparently placed on the friction of the grip between the sleeve heads.

An advantage, however, in connection with these latter four designs is that for larger diameters of commutator, while assuming the same diameter of shaft, it is only necessary to increase the diameters of the washers and nuts, simply leaving a larger air space between the segments and the bush. For very large diameters the bush may be double, being composed of an inner cylinder riding on the shaft, and an outer cylinder carrying the segments, united by radial ribs to the inner one. By this arrangement passage for ventilation is afforded by the space between the cylinders.

We now come to four more designs, Figs. 74 to 78. Of these the first two, it should be stated, we borrow from Prof. Silvanus P. Thompson's "Dynamo Electric Machinery." Fig. 74 is another design by Mr. Gisbert Kapp, and Fig. 76 one by Messrs. Paterson and Cooper. Fig. 77 is another "Westminster" design; and Fig. 78 is a design adopted by Dr. Hopkinson, though with this latter we are not able to show any insulation. Fig. 74 will be seen to be similar to Fig. 73 in having a double sleeve: otherwise it is totally unlike. It is, however, similar to Fig. 78 in simplicity of end slope, and in having very large angles. Fig. 75 represents

Mr. Kapp's latest form of commutator, which we borrow from the very fine collection of plates at the end of the fourth edition of Prof. Thompson's book above referred to. It will be observed that the double sleeves are abolished, only a very fragmentary idea of a second sleeve being represented by a prolongation of the nut. Comparing with Fig. 71, it will be observed that the gaps there lettered *l* are here inside the insulating cones, instead of outside. But this apparently small transposition of the gap is not without effect. It will be seen that it makes all the difference between the circular arch principle of support for the segments, already alluded to, and a solid central bedding. For with the gap inside the insulation, as shown in Fig. 75, the segments are directly supported by the cones at either end, and so cannot fall inwards toward the

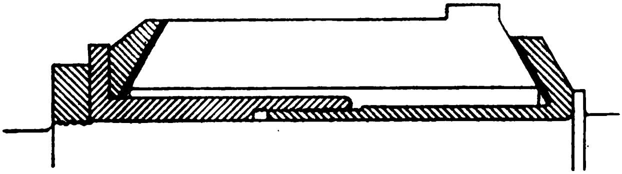


FIG. 74.—Kapp.

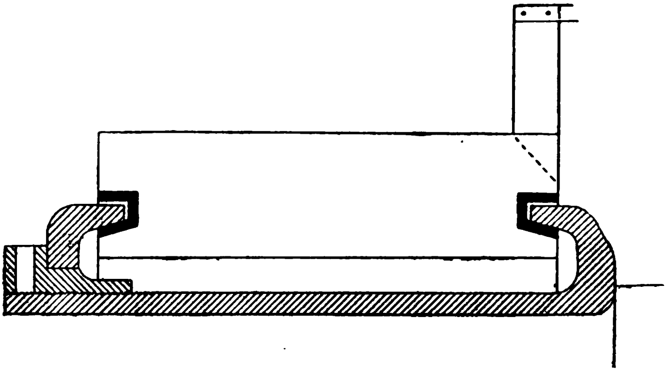


FIG. 75.—Kapp.

centre, and are, in fact, held at a certain rigid pitch or diameter, in the same manner as with Figs. 70 and 72. The washer rides on a shoulder of the nut, and so is centred on it. It may be noted further how that, in accordance with previous remarks, owing to the adoption of an air space for insulation between the segments and the sleeve, and to the supporting of the segments at the ends only, a large diameter may be, and is, reached by simply increasing the diameter of the washer and head.

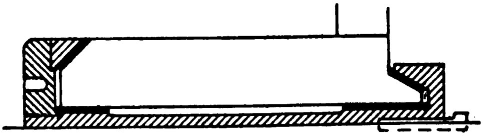


FIG. 76.—Paterson and Cooper.

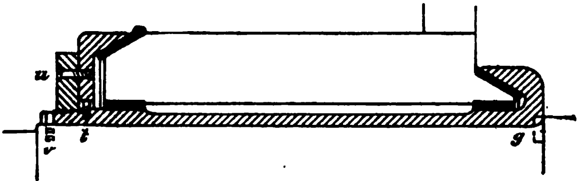


FIG. 77.—"Westminster."

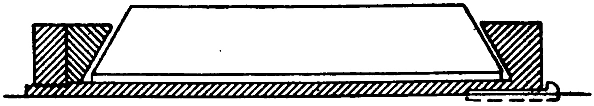


FIG. 78.—Hopkinson.

Figs. 76 and 77 will be seen to have similar segments, and both differ from the remainder in that they have insulation under the ends of the segments only. They thus effect a compromise in this respect between the first four designs and the second four we have illustrated. Bedding on the sleeve is secured without the expense of carrying this the whole length of the segments, and so saving in both machinery and insulation is effected. This method of bedding may be effected with mica, folded round in narrow strips, and in very thin layers: for when very thin, mica is extremely pliable. In Fig. 76 a small washer of triangular section is used, which rides, however, on a shoulder on the nut, and so is centred. In Fig. 77 the washer rides on the sleeve, and is prevented from turning by a pin let into the sleeve, as shown at *t*. The object of this is two-fold, inasmuch as it prevents any possibility of slewing the segments on tightening the nut; and also it gives security for locking the nut by means of the screw *u* put through both parallel with the shaft as shown. Another simple method for securing the same ends is to cast a snug on the inner periphery of the washer, in such a manner as not to interfere with its being turned in the lathe, which shall engage between snugs or in a slot in the sleeve. For the evil of slewing the segments, caused by the washer going round with the nut (when not prevented), and taking the ends of the segments with it, is not an imaginary one; though many makers rely for its prevention on the tight clamping of all the parts together during the process of tightening up the nut. A further distinctive feature about Fig. 77 is that it is put on the shaft without being held there by a nut or nuts at the end. A sufficiently stout steel screw is put in at the end of the sleeve projecting beyond the nut, as shown at *v*, experience, so far as we are aware, justifying this as quite enough. For as there is no conceivable force, at least such as could be anticipated, apart from mere vibration, with a tendency to separate the commutator from the armature, there seems no reason why the simple screw should not be sufficient. This method is, however, not peculiar to the one type we illustrate.

It is essential with all commutators that they be driven direct from the shaft. Hence we find in Figs. 76 and 78 that the sleeve is keyed to the shaft; while in Figs. 66, 67, 71, and 77 a steel pin is driven into the shaft, as at *g*, for this purpose. The nuts, whether of gunmetal, wrought iron, or steel, are usually circular, with radial holes, or else rectangular notches in the rim, for the use of a tommy to tighten up with. But, as shown in Fig. 76, horizontal holes parallel with the shaft may also be adopted; while two flats, one on each side the nut, for the use of a spanner, is another method.

CHAPTER XIII.

COMMUTATORS.—CONNECTIONS WITH ARMATURE WINDING.

THIS chapter we propose to give to the consideration of some remaining items more or less independent of the interior construction of commutators. Some of the various methods in which the lugs are formed, and connection with the armature winding achieved, may thus engage our attention.

As already intimated, the commutator lugs may be either cast in one with the segments, or they may be separate pieces soldered or brazed in. This latter has of necessity to be the method adopted when the segments are of rolled copper, except, perhaps, when, as in cases previously alluded to, the armature is wire wound, and the commutator large in proportion. The lugs when separate are frequently made of two strips of copper riveted together, opening out into a fork at the outer end to receive the winding end. This is shown herewith, Figs. 79 and 80. The nitch in the segment receiving the inner ends is cut out with a small circular saw, which accounts for the rounded corner *a*.

Figs. 81 to 83 are other variations. Here one strip only is used, bent over at the top as shown, so as nearly to enclose the winding end soldered into it; and the inner end, instead of being received in a nitch, lies in a recess at the side of the segment, which may, however, be cut with a saw the same as the nitch. It may be riveted to the segment as well as soldered. A very common way, instead of enfolding the winding end when this is a bar, is to make a saw cut in the bar end to receive the outer end of the lug, as shown in Figs. 84 and 85. The lug is then simply a straight strip of copper,

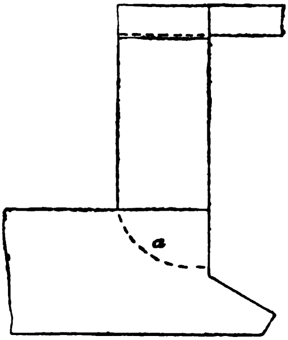


FIG. 79.

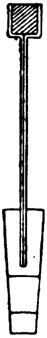
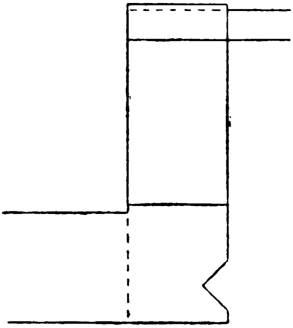


FIG. 80.

FIG. 81.



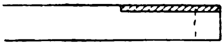


FIG. 82.

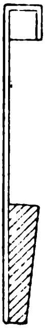


FIG. 83.

received and soldered or otherwise fastened into a saw cut at both ends. In all cases, the outer end of the lug, beside being soldered to the armature bar, may also, as already intimated, be either screwed or riveted thereto.

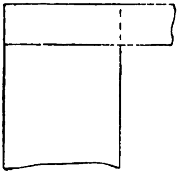


Fig. 84.

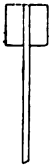


Fig. 85.

A case where rolled segments may be combined with wire winding without the use of additional lugs is illustrated in

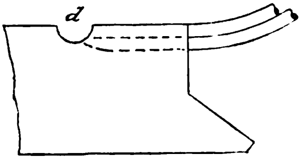


Fig. 86.

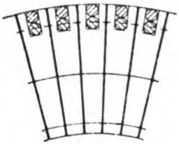


Fig. 87.

Figs. 86 and 87 herewith. *Quasi* lugs are formed by turning a groove *d* in the segments.

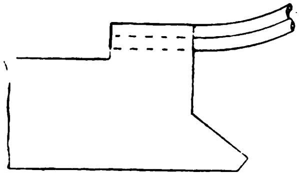


Fig. 88.

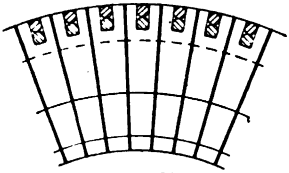


Fig. 89.

Turning our attention now to cast segments, we find a common form in Figs. 88 and 89. Here very short lugs only are necessary, with wire winding, when, as in the previous figures, the wire can easily be bent down to the smaller diameter of the commutator. In the case, however, of bar-wound armatures for heavy currents, where the bar ends cannot be brought down, the lugs must then extend to the full diameter of the armature, as illustrated in Figs. 90 and 91. This looks very neat, the lugs being all turned up bright as well as the brush contact surface. Fig. 92 is a variety where the lugs are sloped toward the armature. This has the advantage of allowing more room for the brush-holder, so that the brushes can bear

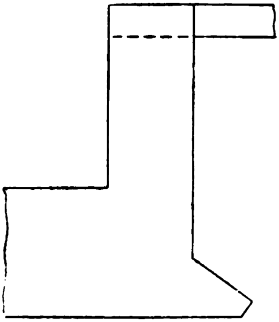


FIG. 90.

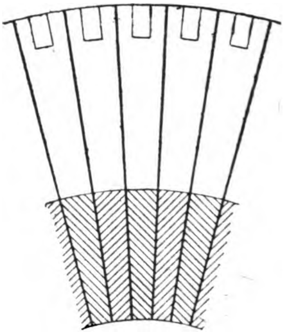


FIG. 91.

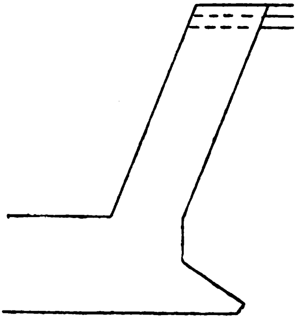


FIG. 92.

right up to the roots of the lugs. It also practically eliminates the short piece of single conductor bar that passes from the armature end winding to the lugs. For this piece, when the brush contact surface is not wider than one segment, has to carry the *whole* current when in sėries with the brush, and being only of a size adapted properly to carry but *half* the current, it would then offer a resistance. Generally, however, this resistance is considered negligible owing to the shortness of the piece; and the bar does not heat as it otherwise might, owing to the fact that it revolves in the open air, and so is kept cool. But another variety of the

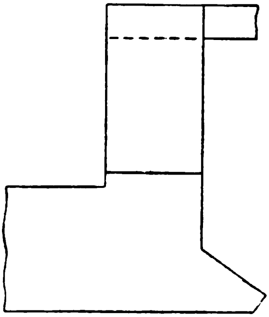


Fig. 93.

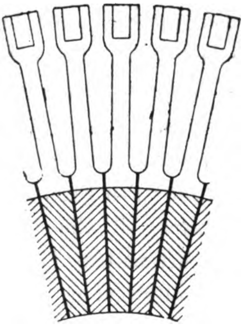


Fig. 94.

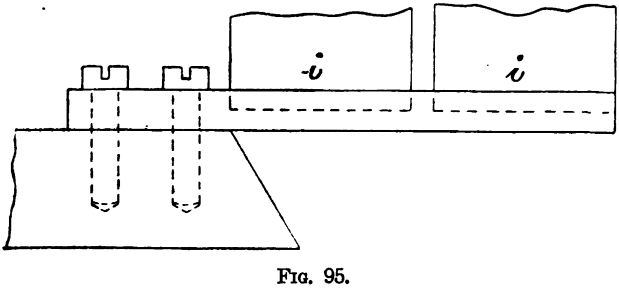


Fig. 95.

same thing is shown in Figs. 93 and 94. Here, it will be seen, the lugs, instead of being carried out solid to the outer periphery, are considerably lightened, and open spaces left between them. This latter arrangement, especially when there is much difference between the diameters of the armature and commutator, must be decidedly more economical. For there is less metal and less insulation than in the former, and labour is saved in not having to machine or file up the sides of the lugs. Ventilation, moreover, is completely stopped in Fig. 91, but not in Fig. 94. A good example, however, of the method shown in Figs. 90 and 92 occurs in the case of the two commutators of the Elwell-Parker motor-generator, or continuous-current transformer, already once alluded to. For here the commutators, especially the high-tension, are abnormally large in diameter. Fig. 95 illustrates a further method of connection, used in the case of the Hopkinson adaptation of the Hefner-Alteneck end winding for drum armatures. Here union is made with the interior ends of the cross connections, instead of to the exterior. Hence a bar, screwed to the segments, and soldered or brazed or otherwise fastened to the ends of the involutes *i i*, is all that is required for the purpose.

CHAPTER XIV.

SPARKING AT COMMUTATORS.—ELEMENTARY THEORY OF ELECTRIC SPARKING.

THE sparking that takes place at the brushes on a commutator is a subject that may now engage our attention in this and succeeding chapters. It is far, however, from being a matter of mere scientific interest to find out what may be the precise cause or causes of this peculiar phenomenon. For, as seen from a practical, not to say a mercantile standpoint, these scintillations, so brilliant to the eye, are none the less a manifestation of so much wasted energy, destruction of material, and loss in capital or dividends. A double object, therefore, each of weight, will attend any investigation into such a subject; and it is hence, with this purpose in view, that we may now proceed.

At the outset of our task various preliminary questions occur, which will have presented themselves in times past, and doubtlessly still present themselves to the inquiring mind in detail. Thus, what are the exact reasons that brushes will spark in one position on a commutator and not another; and why worse in one position than another? Why do some dynamos always spark, but not others? Or, again, why do dynamos sometimes spark, and yet at other times give no trouble in this direction whatever? While a yet further problem of some present day interest relates to the comparative absence of sparking in connection with the use of carbon brushes.

A better solution of these and many other similar queries will be arrived at if we endeavour in the first instance to attain some clear understanding on the subject of electric sparking generally, apart from that in connection with commutators in particular. For it is evident that, without a proper comprehension of the fundamental laws and facts, no really good and satisfactory understanding of more complex portions of the subject ultimately to be arrived at, will be possible.

Thus a first necessary condition for any sparks is that there must be a difference of potential or electric pressure between two bodies, for a spark to pass from one to the other; and such a spark will then flash from the body of higher potential to the lower.

We may now, however, submit electric sparks to a subdivision into five distinct orders. These are as follows:—

(1.) Statical disruptive sparks.
(2.) Induction disruptive sparks.
(3.) Self-induction disruptive sparks.
(4.) Continuous flame, or voltaic arc.
(5.) Continuous disruptive discharge.

The above classification, it will thus be observed, is based on differences, partly in the effects and partly in the causes. We may briefly review these orders separately, before more fully studying them in a greater or less measure conjointly.

The first is distinguished by the fact that it occurs with statical electricity: that is, the electricity which is produced by friction between various substances, such as glass and silk or fur, and resides on the surface of the charged bodies. Two bodies thus charged respectively with positive and negative electricity, or one of them not charged at all, being brought near together, a disruptive spark will flash between them without their being in contact.

A spark of the second class takes place in connection with current electricity, such as is generated by a chemical battery or a dynamo. It is of high voltage and is disruptive, and, like the first, requires no previous contact of the objects between which it passes.

The third, or self-induction spark, is also the result of current electricity, and a high electromotive force between the terminals. It is likewise disruptive, but only follows after previous contact.

The fourth in our classification, or voltaic arc, is a further phenomenon in connection with current electricity. It is preceded by a spark of the third order; but is then dependent on the electrodes not being parted by too great a gap in proportion to the strength of the current and its potential, principally the latter. This latter condition being observed, it has the peculiarity that it continues over a gap too great for the normal potential to send a spark across, in the well-known manner exemplified by the ordinary arc lamp, and contrariwise to the complete cessation of their being, and the infinitesimally small fraction of time occupied by a spark of either the first three orders.

The continuous discharge forming our fifth order is a simple effect in current electricity, where there is a normal very high potential difference between the electrodes. It is disruptive, and requires no previous contact.

We may now, however, subject the above to a more complete analysis, taking the various orders into consideration, not only separately, but as intimated, also in conjunction with one another. Thus, statical electricity, besides residing on the surface, for instance, of jars or brass knobs and so forth, is of extremely high potential—it may be of hundreds or thousands of volts; while the current, if it may be said to have any in passing from one object to another, may only be a minute fraction of an ampere. A peculiarity, moreover, of sparks of this class, even when of great length, and so of great potential, is that they have but little effect on the electrodes they play between, such as the brass knobs of a frictional electrical machine, which only become slightly tarnished. But they are far, however, from being necessarily harmless: for these sparks have this further peculiarity, that they are destructive to any dielectric substance that may be between the electrodes, in the sense that they can *pierce* or *break* and *rupture* any such object. Thus a spark may be made to pierce not only the *air*, but, with a sufficiently high potential difference between the electrodes, also glass, paraffined wood, ebonite, or other such materials. Hence the term "disruptive," as applied to this kind of spark. It is in this direction, indeed, that the destructive effect of lightning is probably to be found. For while a cloud may be a body heavily charged with statical electricity, say positive, the true negative will be the damp interior of the earth. Objects projecting above the ground, such as trees and tall chimneys and so forth, are for the most part dielectric, though perhaps not entirely so, especially in so far as they contain moisture; but in so far as they are dielectric, the large disruptive spark known as a "flash of lightning" has a destructive effect on them in its endeavour to pass by their means to its true negative in the body of the earth; while a good conductor, such as a copper rod extending from the summit of the erection down well into the earth, will not encounter the disruptive qualities of the discharge, and so will escape damage.

Passing the second and third of our orders for the time being in this more particular review, we may now glance at our fourth order—the arc. As a clear conception of the production and continued generation of this form of electrical flame will tend to a good understanding of our subject as a whole, we may consider it with more or less thoroughness. In the first instance, it has to be borne in mind that the carbons in an arc lamp form part of what is termed a "circuit." That is, the electric current, starting from some generator, is conveyed by a conductor (say, a copper wire) to one carbon; it thence passes to the other carbon, and back by another conducting wire to the negative terminal of the generator. In this case, moreover, at least with "continuous" currents, the electricity passes through the *interior* of the conductor, in contradistinction to the manner of the statical electricity, which lies on the surface. With the latter, a "circuit" as above described is not necessary; for there it is a pure case of two bodies charged at different potentials, of which, when they are brought sufficiently near, or are connected, the one higher charged will discharge into the lower one, so that both become of equal potential. This may be likened to the case of two tanks of water at different levels; when connected by a pipe the water in the higher one will flow into the lower till both are of the same level. But there is nothing of the nature of a circuit; and when the water in both is of the same level, the action ceases. Current electricity, on the other hand, may be compared to the case of hydraulic distribution of power, wherewith the water is pumped by engines into a series of pipes which convey it to various points where its energy may be utilised, as for working lifts and hoists, and thence bring it back to the suction of the pumps once more. It *may* be brought back to the pumps, that is. For after having been used, it can be run to waste, or returned to the earth instead, and fresh water be pumped into the pipes. The *earth* may then be said to be the return half of the water circuit. For as the used up water is returned *to* the earth, so is the fresh water drawn originally *from* the earth. It is thus also with electric currents, though in practice only with weak currents, such as are used for telegraphing purposes.

The return half of the circuit may be the earth instead of another wire or "lead."

Reverting, however, to the arc, we find the explanation of this phenomenon, which we take from Prof. Silvanus Thompson's "Elementary Lessons in Electricity and Magnetism" (though we use our own words), to be as follows:—On the carbons being duly connected up in a circuit as described, they are first allowed to be in contact at their points. A current, which experience shows should not be less than 5 amperes as a minimum, or at a less pressure than 40 or 50 volts, is started through the circuit. The carbons are then drawn slightly asunder. At the first instant a self-induction spark of the third order of our classification, to be dwelt on later, flies from the positive carbon to the negative. This is accompanied by great heat due to the current, which volatilises into gas some particles of the opposing carbons. If now the carbons be drawn not too far apart, this gas will form a conductor for the current from one electrode to the other. The precursory self-induction spark being spent, and the current now flowing continuously through this gas, intense heat is developed owing to the high resistance of the latter. This causes the points of the carbons to become white hot, whence arises the light. They are thereby also slowly consumed; and it is to be noted that the *positive* carbon, or that *from* which the current flows, burns down at twice the rate of the negative. The current flowing continuously through the gas from one carbon to the other, in appearance like a blue ambient flame, thus forms what is known as the voltaic arc.

A marked difference will thus here be noted between the arc and the disruptive spark already enlarged on. For, contrary to the case of the spark, the *electrodes* are here distinctly subject to destruction. A body between the electrodes—that is, within the arc—will also be destroyed, however, though not by any form of disruption as with the spark. But the intense heat of the arc will burn, melt, or volatilise, almost if not quite every known substance.

Now, as explained, the arc is immediately preceded by, and has for one of its own pre-existent causes, a spark of the third order. To this latter, and the second order, we may now give our attention. Induction and self-induction sparks, like those of the first order, are disruptive. But they differ from the first, not only in being effects of current electricity as intimated, but further in that they have their origin in *magnetism.* This we may now proceed to make more clear.

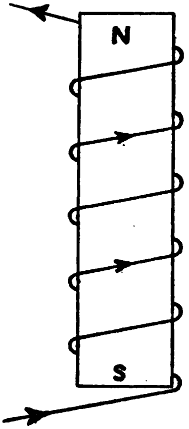


Fig. 96.—Elementary Coil.

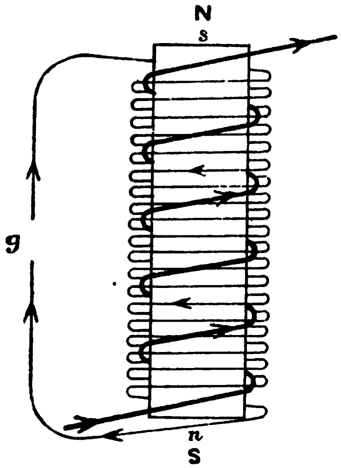


Fig. 97.—Induction Coil at "Make."

It is well known that if a coil of wire be made as shown in Fig. 96 herewith, and a current of electricity be sent through it, a magnetic field will be formed within the coils. If the direction of the current be as indicated by the arrow heads, then, according to Ampère's well-known law, the polarity of the field thus formed will be as also shown by the letters **N** and **S.** Should the current be reversed, the poles will also be reversed.

Moreover, on an iron bar being enclosed within the coil as depicted, the magnetic effects will be still greater, owing to the iron having a much greater magnetic permeability than air.

In Fig. 97 are shown two coils, one within the other, having a common centre line, and also enclosing an iron core. Now, especially when an iron bar is enclosed as represented, a further effect may here be realised. This is, that if a *sudden* current be sent through one of these coils, say the interior one, it will *induce* a sudden current running in the *opposite* direction in the other coil. Further, on suddenly breaking the primary current in the interior, a sudden current will again be induced in the outer or secondary coil, but this time in the *same* direction as the primary current, as shown in Fig. 98. In Fig. 97 the induced secondary current tends to produce a polarity opposed to the polarity of the primary coil, as shown by the small and large letters; while in the case of Fig. 98, the secondary polarity augments the primary. But the point

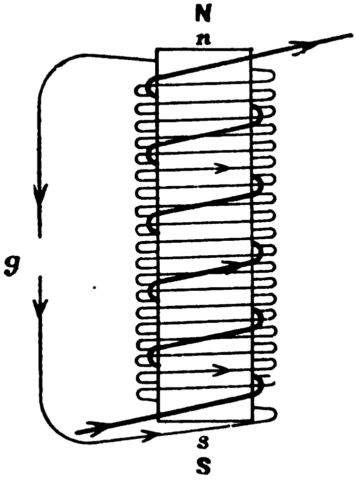


FIG. 98.—Induction Coil at "Break."

immediately to be arrived at, is that this *secondary* current is purely a *magnetic* effect—that is, a result obtained through the intervention of magnetic induction. On this we may yet further enlarge.

In Figs. 99 and 100 is shown a simple armature coil in a field between two poles **N** and **S**, which may be revolved about an axis $x\,y$. Now, in Fig. 99, where the coil is shown quite vertical, and so with its plane normal to the lines of force running from **N** to **S**, if the coil be rotated in either direction, by which motion the number of lines of force it encloses is being *diminished*, a current will run round it as shown by arrow heads. Its polarity also (as in Fig. 96) will be as indicated by the small *s* and *n*. In the case of Fig. 100, however, the coil is represented by the curved arrow as rotating from a horizontal position to a vertical. It is thus *increasing* the number of horizontal lines of force that can pass through it. The result is that a current will course round it, but in the opposite direction to that in Fig. 99. Now, a point to be noted is that in Fig. 99, the *n* and *s* poles of the coil are *attracted* by the respective **N** and **S** poles of the field that they oppose, and hence will offer opposition to the rotation of the coil. In Fig. 100 also, it will be seen that in conjunction with

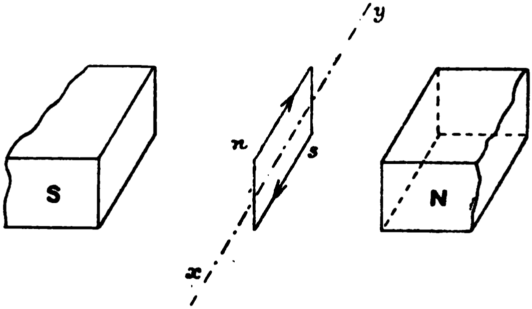


FIG. 99.—Lenz's Law Illustrated in Elementary Dynamo Coil.

the direction of rotation, the *s* and *n* poles of the coil are being brought nearer to the **S** and **N** poles of the field, from which they are naturally repelled. Hence here also there is opposition to the revolution of the coil. The opposition to the rotation, which in these cases is the necessary cause of the current in the coil, and so of the polarity of the coil, thus illustrates Lenz's law, that *any primary cause for an induced electric current produces effects which tend to eliminate such primary cause.*

We may now return to Figs. 97 and 98. It should be mentioned first that the iron core is supposed to be without magnetism

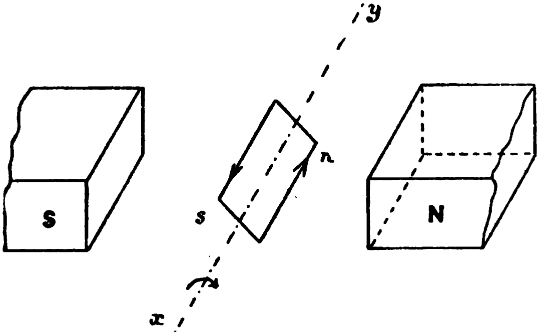


Fig. 100.—Lenz's Law Illustrated in Elementary Dynamo Coil.

when there is no current flowing round it. In Fig. 97 we find the sudden influx of the primary current causing the lines of magnetic induction within the core to rise in number from zero up to a certain maximum. This increase in the lines of *magnetism* is now the real cause of the current generated within the outer secondary circuit, running round in the opposite direction to the primary, as shown by the arrow heads; precisely as an increase is a cause of such an effect in Fig. 100. The result of this, again, is that the secondary current tends to produce poles *s* and *n*, which are contrary to the primary:

that is, to eliminate the very influx of magnetism by which the secondary current is itself called into existence.

Now, while the primary coil may be of a few turns of stout wire, the secondary may be of a large number of turns of fine wire. The potentials of all the turns of the secondary being accumulated, forms an enormously high total electromotive force between the ends of the secondary, brought near together as at *g*. This distance not being disproportionate to the electromotive force, a disruptive spark will strike across in the direction of the arrow heads at the instant of the sudden increase of the magnetism of the core. The primary current continuing steady, and there being no further alteration of the magnetism of the core, there will be no continuance of current in the secondary, and nothing more will happen except that the full strength of the primary current and the polarity of the core become established after the cessation of the resistance thereto offered by the secondary. But if the primary circuit be now suddenly broken, there will be an immediate decrease of magnetism in the core, from maximum to zero. This will cause a current to flow round in the same direction as the primary, as shown in Fig. 98, contrary to the manner in Fig. 97. A disruptive spark will fly across at *g* again, but in the opposite direction to that in Fig. 97. The secondary here will cause a polarity identical with that of the primary. It hence tends to maintain the primary polarity, while it is to the very fact of the *decreasing* of this magnetism that it owes its own existence. We thus see in these two cases a still further exemplification of Lenz's law as above enunciated.

Now, the sparks that take place at the gaps *g* in Figs. 97 and 98 are induction sparks pure and simple, such as belong to our second order. They are disruptive, and would do more damage to a dielectrical substance in the gap than to the terminals at either side. As explained, their electromotive force would be very high, and the current extremely small. The potential difference, however, between the terminals will depend, as in the case of an armature winding, on the *number* and on the *rate* of the increase or decrease of magnetic lines, and on the number of turns in the secondary coil. Thus, with a given rate of making or breaking the primary circuit, a compound coil, large in diameter so as to enclose many magnetic lines, and with a great number of convolutions in the secondary coil, will obviously generate a much higher electromotive force than one of smaller size, and with fewer turns in the secondary. Transformers, or converters, as they are variously termed, exemplify this kind of induction. A low tension *alternating* large current in the primary coil, consisting of a small number of turns of *thick* wire or copper bar, induces an alternating high tension small current in the secondary, having a large number of turns of *fine* wire; or *vice versâ*. The resistance caused by the fine wire, it will be noted, keeps the secondary current small, though its electromotive force may be high. In the high-tension experiments by Messrs. Siemens Bros. and Messrs. Swinburne and Co., at the Exhibition at the Crystal Palace in 1892, wherewith pressures of 50,000 and 130,000 volts respectively were attained, it was in this manner that such results were arrived at. Powerful disruptive sparks were emitted between electrodes; while owing to the presence of an appreciable current also, enormously long arcs, 2ft. or so in length, could be maintained. It is further to be noted here also, that owing to the normal potential being already so high, preliminary contact between the carbons was not required. The precursory spark of the arc was of our fifth order, and not our third order, as is usual with the arc. For here, on the carbon points being brought within about 3 inches of each other, the current would immediately leap across, after the manner of that order, with which we shall deal in due course.

As we have stated, however, the above refers to induction sparks only, which are caused in a *different circuit* to that of the primary. But sparks similar in nature, and based on the same laws, may be obtained in the primary—that is, within any circuit itself. Such sparks, with cause and effect taking place within the same circuit, are the result of what is called the *self-induction* of that circuit, and we may hence style them self-induction sparks. These, forming the sparks of our third order, may thus now engage our attention.

CHAPTER XV.

SPARKING AT COMMUTATORS.—SELF-INDUCTION AND ELEMENTARY THEORY CONTINUED.

FIG. 101 shows diagrammatically a complete circuit, including a coil with iron core. A generator is indicated at *a*, and a gap which can be closed at *g*, while for the present the dotted line *c c* may be disregarded. Now, a current flowing steadily as represented by the arrow heads, will cause the same polarity of the coil here as in Fig. 96; though this would of course be only when the gap *g* was closed, as otherwise the circuit would not be complete. Let it now be imagined that in the first instance the gap *g* is open. There will then be no current flowing, and so no lines of magnetism within the coil. Suppose, then, the gap to be suddenly closed. We may note the immediate effect. A sudden generation and increase of lines of magnetic induction will take place within the coil, which will exercise a counter tendency to make the current flow round the coil in the *opposite* direction to that shown. It will thus momentarily retard the full establishment of the normal main current. But the full current becoming at length established, let the gap *g* be suddenly opened. The result will be a cessation of the main current, with consequent decrease of magnetism within the core. But a sudden decrease of magnetic lines will cause a current to flow round in the same direction as the main current. Hence at the moment of breaking contact, the main current is reinforced with more or less strength and difference of potential, according to the dimensions of the coil and the rapidity of the break. In consequence, a disruptive spark, due to the sudden and great increase of potential between the opposing ends, will take place at *g*, leaping across in the same direction as the main current, as in Fig. 98. Yet further, inasmuch as we are dealing here with the main current itself, and not a secondary, if the points at *g* (Fig. 101) are not pulled too far asunder, the current may continue crossing the gap as an *arc*, in the manner already described. It is to be noted that in the cases of Figs. 97 and 98 these self-inductive retardations do actually take place in the primary coils; and while induction sparks are produced in the secondary, self-induction sparks may be produced at the moment of break in the primary.

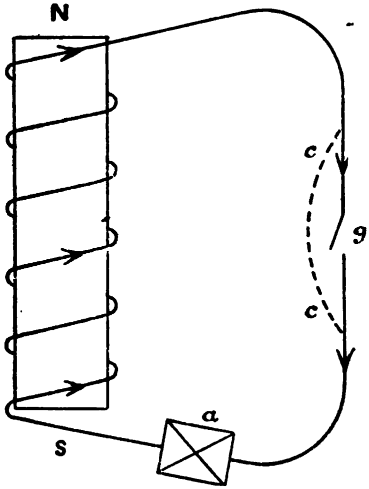


FIG. 101.—Diagram Illustrating Self-Induction.

We thus find in the case of a self-induction spark the effect of Lenz's law again. For the momentary counter current tends to retard the cessation of the main current, although it is the very act of this cessation to which the counter current and the sparks owe their existence. But, as already intimated, these induction and self-induction effects are entirely due to the intervention of magnetism. It is thus that the phrase "electric inertia" is not a safe one to use instead of "self-induction." It is not the *inertia* of the current *per se* that causes it to fly on after a break of contact, and cross the gap in a spark. A high electromotive force may accumulate at the positive electrode at the break; but this is not, correctly speaking, analogous to the high-pressure that may occur behind a valve in a pipe containing water flowing under pressure, when it is suddenly closed. In this latter such pressure is due to the *momentum* of all the water behind the valve, which is suddenly brought to a stop. Momentum implies *weight*. But there appears to be nothing whatever of the nature of weight in the electric current. Hence the cause or causes of effects manifested by an electric current that might seem due to something like momentum must be looked for in an earlier state of things. This is made clear by the fact that if the wire circuit, as in Fig. 101, be pulled out so as to form a simple circuit without any coils in it, and with the iron core also absent, there will be scarcely any self-induction left; and on breaking the circuit at the gap there will be little or no spark, although the actual total length of the wire is unaltered. Thus the absence of any accumulation of electromotive force at the positive electrode in this latter case, shows that there is not anything akin to momentum in the electric current, as with the flowing water suddenly stopped by the valve. With the coils it is a pure case of a sudden *generation* of an extra electromotive force in accordance with the laws of magneto electricity, already dwelt on. This newly-generated electromotive force, impelled by the magnetic forces to which it owes its origin, rises to so high a potential in the positive electrode at the moment of break—it may be to some hundreds or thousands of volts—that it is able at the instant to send a disruptive spark through the air and across the gap in the manner described.

We may turn now to the fifth order of sparks which we have assumed. It has been stated that the sparks of the first three orders are the effects of a high potential difference between the electrodes; though in the second and third orders this will be higher than normal. Our classification is, however, based on the causes rather than on the effects themselves. Thus, our fifth order of sparks are those that result from a high potential of the normal or main current itself, without any magnetic or other augmentation. It is again an effect of current electricity. Two electrodes, for instance, in a circuit of either continuous or alternating current electricity, of say 10 amperes and 20,000 volts pressure, if held a few millimetres apart, would have a continuous disruptive discharge passing between them from positive to negative, and that *without previous contact.* This latter characteristic thus alone would distinguish it from an arc. But their brilliancy, as compared with the low luminosity of the arc, that is, of the arc itself, disregarding the intense light from the white hot carbons, and the absence of the intense heat of the latter, together with a difference of the sound produced, would form further distinguishing features. This fifth order, moreover, is not to be confounded with the stream of sparks that may be obtained from a Ruhmkorff or other induction coil. For these latter belong to our second order, having for their cause magnetic generation.

This continuous disruptive discharge of our fifth order, and indeed all disruptive discharges, have however a yet further distinct difference from the arc. This is, that they take the most straight and direct course to the negative. An arc, especially of any length, is easily made to take a circuitous path; as, for instance, in the experiments by Messrs. Siemens Bros. at the Crystal Palace, already alluded to. For here the electrodes, instead of being held the one vertically over the other in the usual manner, were held level with each other in the same horizontal plane. Being also about a foot or 18in. apart, the arc then rose from the one 18in. or 2ft. upwards, coming down again to the other electrode, thus forming the shape of a horseshoe or arch. Yet this great divergence from the straight line to the other electrode was chiefly caused by the air draught due to its own heat and the mutual repulsion of its different parts. The arc, moreover, in this case, was not of a smooth regular form like, for example, a rainbow, but waved and oscillated, and behaved in a manner that may be better likened to an arched blue flame of fire. The rupturing character, on the other hand, of the disruptive discharges, is entirely due to their intense proclivity to adopt a straight course. Hence, rather than be turned aside by any obstacle that may be in the way, they prefer to break it up or pierce it, and so attain their desired consummation.

Our attention may now be directed to some special points. We have spoken of disruptive sparks and arcs, of current, and electromotive force, or potential. Some effects in particular, however, may be noted. When dealing with the formation of the arc, we mentioned the great heat as being due to the current. A high voltage, with or without much current, produces on communication what is called a "shock," best made analogous perhaps to a vibration more or less terrific, according to its strength. But the current burns. A large current at a very low voltage will produce scarcely any "shock," but may produce great heat. This latter, however, depends on there being a resistance to its flow. A resistance being offered, the work done in overcoming it is the immediate source of the heat that will be manifested. If there be little or no resistance, there will likewise be little or no heat.

Now there is always *some* heat with every kind of spark; but the point we wish to arrive at may be made more clear perhaps thus. Suppose an animal is to be killed by electricity. It may be put in a circuit with a high voltage and small current, say 20 amperes at 2,000 volts. On switching on the current, it is struck dead instantly by the "shock" due to the high potential; while the body subsequently may show no signs of burning, for it will not have offered sufficient resistance for the small current to take effect. On the other hand, if intense heat be desired to burn or melt any otherwise refractory substance, large currents are required. Thus, we find in the case of electric smelting furnaces, wherein the intensest heat is obtained by means of the arc, that extremely large currents of even 12,000 or 14,000 amperes are used: while there may be only an electromotive force of 30 to 60 volts. Thus we observe that it is to the presence of *current* that heat is due in an arc, with all its concomitant effects, such as burning, melting, and volatilisation; and it should be noted that the resistance that gives rise to the heat is not that due to the substance being acted upon, but to the arc itself: hence the comparative lowness of the electromotive force.

We have already dwelt on the destruction of the electrodes of an arc. This, however, is not the only source of expenditure in either material or energy. For it is supposed that a back electromotive force is set up in the arc, which impedes the flow of the normal main current. Hence, besides the energy necessary to overcome the resistance of the gas which is the product of the volatilisation of the carbon, energy is also spent in overpowering this back electromotive force. A complete theory of the arc would, however, appear to be wanting. But at the British Association meetings in Edinburgh in 1892, a Paper on the subject was read by Prof. Silvanus P. Thompson (see *The Electrician*, Vol. XXIX., p. 460), should any feel interested in knowing more. Further, however, when considering the arc and its generation, we have observed that it is commenced by a disruptive spark, which may be of either our third or fifth orders, accompanied by great heat, due principally, as we now find, to the presence of the current: for a statical electric spark, wherewith there is practically no current, does not cause much heat. A further point, however, to be noted, is the extremely small amount of time occupied by a disruptive spark. This is, in fact, infinitesimal; the time taken by so great a disruptive spark as a flash of lightning being at the most only about the hundred thousandth part of a second.

We have now reached that stage in our progress, however, when we may bring the above to a practical bearing. Thus we may consider what happens on the opening of an electric switch such as is in common use. When this is done, usually a flash is seen. Moreover, the switch may so be held that an arc is maintained between the moving tongue or contact piece and the fixed contact piece. But allowing it to be opened quickly, even by the means of some spring snap arrangement, the opening will still take a very appreciable amount of time compared to the extremely small period required for the spark. No switch could endure, whereof the moving parts moved with a speed even approaching that of a flying bullet.

The upshot, hence, in the case of a flash seen at the opening of a switch, is that, whereas this may have for its commencement a self-induction disruptive spark of our third (or fifth) order, the remainder of the flash will be a momentary arc due to the current; and the greater the current, the greater will be the deflagration.*

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* This point of the brilliancy of the flash, or the deflagration, depending on the quantity of the current, and also that of the intensity of the shock depending on the E.M.F., may be found fully discussed in the earlier part of Chapter IV. of Prof. J. A. Fleming's book on "The Alternate Current Transformer," Vol. I.

Now we found when examining the arc between two carbons, that the precursory spark volatilised some particles of carbon; that is, heated them so intensely as to turn them to gas. Further, we noted that on the establishment of the arc both carbons were burnt, owing to their oxidisation in the air; but the positive carbon at twice the rate of the negative. Now, metals will volatilise more easily than carbon; and moreover, they also oxidise when heated and exposed to the air, even when not fused. Hence, in the case of the flash seen with the switch, and drawing our inference from the arc between two carbons, we find that both contacts are exposed to destruction. Firstly, some of the metal will be volatilised by the precursory spark; and secondly, the positive contact will be burnt and oxidised away at twice the speed of the negative by the following momentary voltaic arc. This, however, assumes an ordinary current, such as may be large enough to maintain an arc, and an ordinary electromotive force of but a few hundred volts at the outside. In the case of very high voltages, and a current too low practically for an arc, the flash on the opening of a switch would be a momentarily continuous disruptive discharge of our fifth order. Both contacts may consume away somewhat, owing partly to their oxidisation on being heated and partly by volatilisation. But returning to the case of a switch in a circuit where there is an appreciable current, we find this peculiarity, that, inasmuch as in point of the time taken by the flash by far the larger proportion is occupied by the arc, it is the arc that works the greater destruction, chiefly to the positive electrode.

Having thus far entered into the subject generally, we may now perhaps consider ourselves the better prepared to examine with some closeness what is our main subject—the sparking that takes place at the brushes on a commutator.

CHAPTER XVI.

SPARKING AT COMMUTATORS.—THE ELEMENTARY PLANES THROUGH COMMUTATOR AND ARMATURE.

COMMENCING now to give our attention to the sparking that takes place at commutators particularly, it may be well if at the outset we consider what are the conditions that usually obtain with a commutator of a well-made dynamo. For simplicity's sake, we will refer only to the case of an ordinary two-pole machine, of a closed-coil type. Such a case is represented diagrammatically in Fig. 102 herewith. It will be observed that a horizontal field is shown, with the north pole-piece on the right-hand side, and the direction of rotation of the armature as indicated by the curved arrow; and, to avoid confusion, we will assume these conditions throughout. The commutator segments are denoted by the letters *c c*, and the radial lines *b b* indicate the coils or sections of the armature winding, which may be either drum or Gramme, and short intervening radial lines represent the lugs connecting the winding to the commutator.

Now, it was explained in connection with the armature winding in our first chapter, that in the course of the generation of current and electromotive force under the above conditions, the coils of the armature winding which are nearly or quite horizontal, as at *w x*, generate the most potential;

for they are here including or excluding the horizontal lines of force of the field at the greatest *rate.* Hence each segment of the commutator connected to coils in this position will have its potential raised above that of the one below, by an amount equal to the potential gathered by the coil or section of winding that connects them. Thus there will be a *maximum* potential difference between adjacent segments at the *sides* *w* and *x*. But the coils that lie in planes nearly or quite vertical, as at *y z*, are practically not including or excluding lines at all: hence they generate no potential. Consequently, there will be a minimum, or practically no potential difference between their commutator segments; and the potential difference between any two adjacent segments will increase as the plane of their connecting armature coil leaves the position normal to the lines of force of the field and approaches a position parallel to them; and *vice versâ.* Nevertheless, on one side of the commutator, say at the top, there

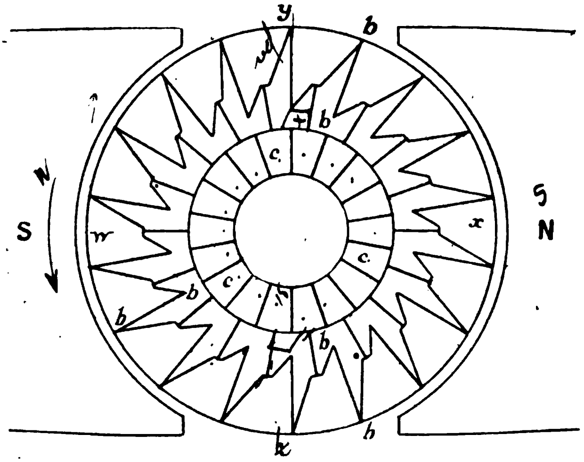

FIG. 102.—Diagram showing Commutator, Armature Winding and Field.

will be a maximum potential, and at the lower side, a minimum potential.

Now, a plane through the axis of rotation, also containing

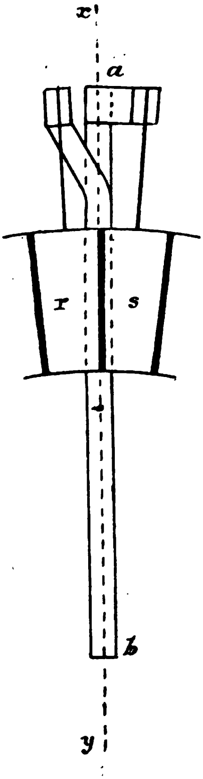

Fig. 103.—Plane of Coil between two Commutator Segments.

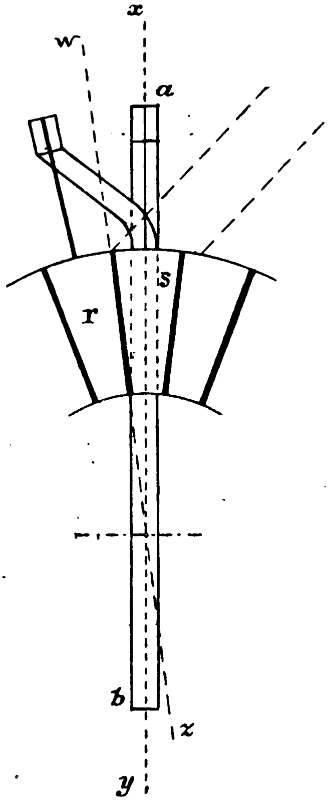

Fig. 104.—Plane of Coil Cutting through one Commutator Segment.

the coil, or section of the winding, connected to the segments on which the brush rests, is known as the "plane of commutation." For it is herein, as the armature coils successively arrive into it, that they change the direction of the current within them, or are "commuted." It needs to be clearly understood, however, that this plane appertains to the *armature winding* only. The segments of the commutator may lie in or about the same plane as the coils to which they are connected, as in the case of Gramme winding; or with drum winding (approximately), when the parallel conductor bars on the armature run straight out to the lugs of the commutator. Or the segments may be at right angles to their connecting armature coils, as with drum winding, when the connection with the commutator segments is made from the interior of the end-winding—that is, from the middle of the cross connectors, instead of from their exterior ends. This interior connection was exemplified by the Hopkinson and Eickemeyer end-windings illustrated and described in Chapters VI. and VII. Figs. 103 and 104 will, however, make the matter yet more clear. In both of these $a\ b$ is an armature coil seen endways, extended in a plane $x\ y$. But in the former we find this plane cuts exactly *between* the segments r and s to which the coil is connected: while in Fig. 104 it cuts through the segment s. The latter is perhaps more usual in dynamo construction.

It is from this point, however, that we shall now need somewhat to enlarge. Having thus far made allusion to what is termed the plane of commutation, it will be necessary to expatiate more fully in this direction.* For in order to arrive at a good understanding of our subject as a whole, we may assume five other such planes. These, together with the plane of commutation, may be enumerated as follows:—

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* This subject is discussed in Prof. Silvanus P. Thompson's "Dynamo-Electric Machinery" (pp. 82 to 86: fourth edition). We have ventured, however, to carry the analysis still further, and to put the subject, as it were, under a greater power of the microscope. Points, we trust of interest, may thus be made to appear, not otherwise discernible.

(1) The plane of commutation. (Cn P in the diagrams.)

(2) The neutral plane, or plane of non-sparking. (N P.)

(3) The plane of requisite reversal. (R R.)

(4) The plane of maximum E.M.F. through the commutator. (M′ M′.)

(5) The plane of maximum E.M.F. through the armature. (M M.)

(6) The plane of cessation of force. (C F.)

We thus discover here six different planes—each of which possesses its own special characteristics. So many may perhaps appear confusing, yet their elucidation is not difficult, and may at once be undertaken.

At the outset, hence, it is to be remarked that the first three planes are entirely concerned with the *current*, and the remaining three with the *potential*, alone. One in each set of three, (2) and (4), appertains to the *commutator*, and the other four to the *armature*. In the accompanying diagrams, Figs. 105 to 108, these planes are indicated by lines having the letters assigned to each in the above enumeration; and for the sake of simplicity, the assumption in these diagrams is that, as in Fig. 103, the plane of the coil cuts the edge of the receding segment *r*. We may now proceed briefly with their several definitions.

The first, or plane of commutation, already slightly touched on, may thus be more precisely described. Inasmuch as the act of the reversal of *current* in a coil cannot take place—that is, from full strength in one direction to full strength in the other direction—without *some* expenditure of time, however small, this plane of commutation may be considered as occupying that position wherein the coils, as they arrive into it. have an infinitesimally small amount of the reverse *current* commencing to flow in them. Practically, this is, of course, tantamount to saying that it occupies a position where there is *no* current in the coils. Further, however, it has to be understood that this plane is *not a fixed element* in the dynamo; for its position is governed by the brushes, which are movable. This is illustrated in Fig. 106, which shows the planes as they become arranged when the brushes are shifted back. It will be observed that the Cn P plane follows the brushes, though with some degree of elasticity, inasmuch as it now passes through the points instead of the heels. This latter incident will, however, be explained in a future Chapter (XX.). We have italicised the word *current* above, for indeed this commutation of current is not to be confounded with a change of *electromotive force*, which is a distinctly different matter. This latter phenomenon is a characteristic of the sixth plane, to be dealt with presently, and, as we shall see, the *current* in a

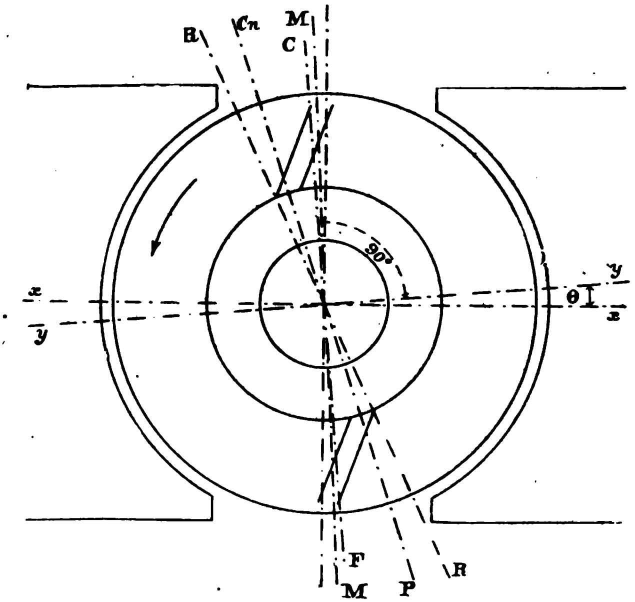


Fig. 105.—Armature Planes. *Positive* Lead to Brushes.

coil may flow quite counter to the *electromotive force* of that coil.

Now, whereas the plane of commutation had to do with the armature coils, the neutral or non-sparking plane, the next in our order, has to do with the commutator. This is indicated by the letters N P in Figs. 107 and 108. As its name implies, it is that plane through the axis of the commutator, which contains the line on each side, where, if the brush points are resting there, no sparking occurs. Unlike the last, it is an invariably *fixed* element in a dynamo—that is, normally and with a steady load. It does not move with the brushes, but contrariwise, has to be found by shifting the brushes to and fro, and so by experiment noting the position where no sparking

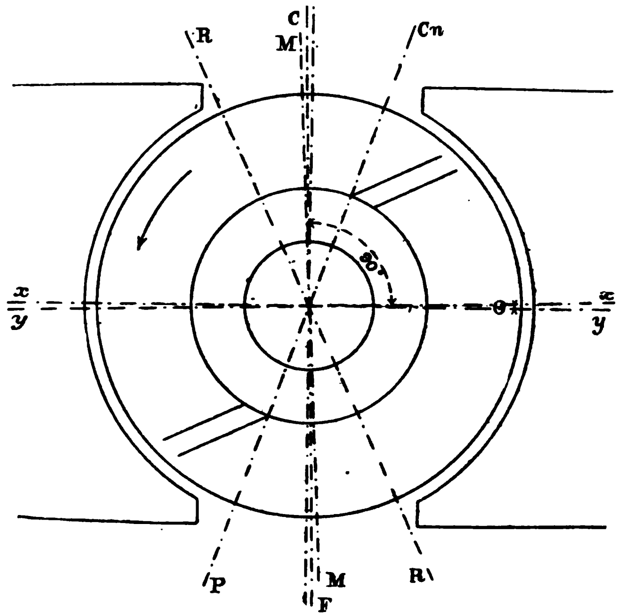


Fig. 106.—Armature Planes. *Negative* Lead to Brushes.

takes place. Of course, in some dynamos there is no such position, or at the best, only a point of minimum sparking. But to this we shall return.

The third plane, or plane of requisite reversal, though distinct from, is yet intimately connected with, the neutral plane. For when a brush is at the non-sparking point on the commutator, this third plane is that occupied by the coil which connects the segment that is in the act of receding from the brush point with the immediately following segment on which the brush rests. Similarly to the two foregoing, the *current* alone is here concerned; and it will be perceived that this plane is an element of the winding. It is also a normally fixed plane, and lettered R R in the diagrams. As regards its

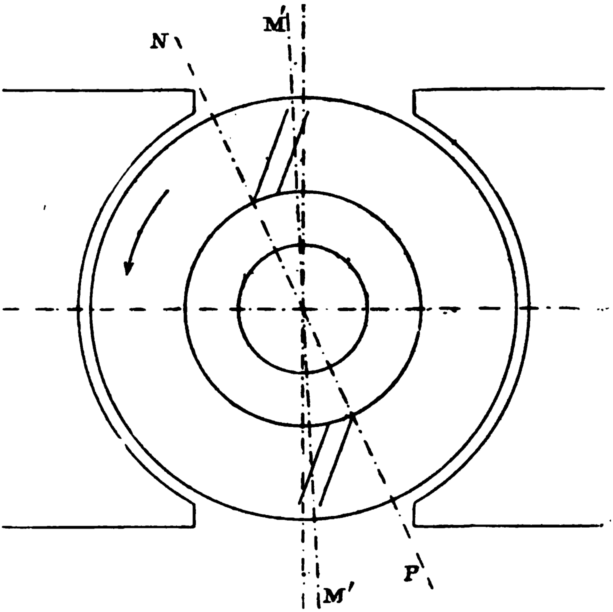


FIG. 107.—Commutator Planes. Brushes at Non-Sparking Points.

fixity, in fact, it accords with the neutral plane of the commutator: and, depending entirely on construction and the method of connecting up the armature winding with the commutator, it *might coincide* with the neutral plane. This latter, however, would only occur when, as in Fig. 103, the plane of the coil divides the two segments to which its ends are connected, or, more accurately, when it passes through the edge of the receding segment *r*, as shown. Otherwise, the two planes will be distinct, though at a mechanically fixed and invariable angle with each other, as illustrated in Fig. 104, where *w z* may represent the neutral plane, passing through the edge of segment *r*, and at a fixed angle with the plane of the coil *x y*; and also exemplified by the angle β in Fig. 108. It is necessary

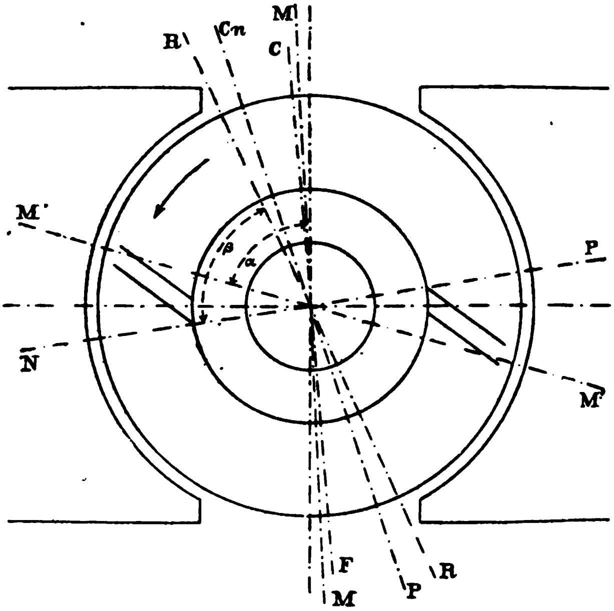


FIG. 108.—Diagram showing all Planes, with Brushes at the sides.

to postpone a further explanation of this third plane, however, until we can bestow more ample attention on it in the next chapter.

We now come to the consideration of the last three planes, which have to do simply with the potential. The first of these, No. 4 in the enumeration, is an element of the commutator, as already intimated. It is represented in Figs. 107 and 108 by the line M′ M′, and is that plane through the axis of the commutator which contains the points on either side where there are respectively the maximum and minimum potentials. When the brushes are at the non-sparking points, then this fourth plane would lie behind, as shown in the diagrams. It is normally a fixed element not movable directly with the brushes, and with a steady load, should not vary in position.

We now arrive at the fifth in our order, the plane of maximum electromotive force through the armature. This applies to the armature, as the fourth applies to the commutator. It is indicated by the letters M M in the diagrams. When the brushes are at the non-sparking points on the commutator, this plane would come more or less behind the plane of commutation, and consequently still further behind the plane of requisite reversal, as shown in Figs. 105 and 108. As with the second and third planes, so the coincidence of this fifth plane with the fourth is a pure matter of construction, and would, in fact, take place when the second and third coincided, as in Fig. 103: or otherwise the two planes would be at a mechanically fixed angle with each other, as lettered *a* in Fig. 108, or as illustrated in Fig. 104. The condition depicted in Fig. 103, however, being assumed in these diagrams, it will be observed that if Fig. 107 be superposed on either Figs. 105 or 106, the lines N P and M′ M′ would coincide respectively with R R and M M.

It is thus that when the brushes are resting on segments in the M′ M′ plane of the commutator they will gather the highest

E.M.F.; or, in other words, there will then be the maximum potential difference between the negative and positive brushes attainable with the machine. But sparking would thereupon ensue; and hence, on moving the brushes forward to the non-sparking points in the neutral plane, a loss of E.M.F. is sustained. It is therefore desirable that the angular distance of the N P plane should be as little as possible beyond the M′ M′ plane, which is to be achieved, as we shall find, by making the field very strong in proportion to the armature self-excitation.

This is, of course, another way of intimating that in a good machine the brushes will require very little lead. On the other hand, as pointed out in connection with Figs. 103, 104 and 108, the M′M′ plane itself may be inclined, and so not normal, to the field, as a simple result of mechanical construction, so that the large lead given in such a case to the brushes would be more apparent than real; while further, by the same means, just the opposite results may be obtained, and the machine made to appear as though its brushes required little or *no* lead. This is doubtless the case in some machines, wherein the armature winding is so arranged that the coils are in advance, in the direction of rotation, of the segments to which they are connected. The armature planes will be ahead of the commutator planes, and the N P plane becoming at or about normal to the field instead of being in front, the *appearance* of little or no lead will result. What inference may be drawn, however, is simply that the position of the brushes at their non-sparking points, as seen by the eye, is no criterion of the real lead. A distinction in fact may be drawn between apparent lead and true lead. But the position of maximum E.M.F. can be determined with a voltmeter, and the advance beyond that to the non-sparking position will then give the true lead.

We have now, however, to consider the sixth plane, which we have termed the plane of cessation of force. This is, indeed, the plane of commutation for the *electromotive force* of a coil, in contradistinction to the plane of commutation for the *current*. But as the term "plane of commutation" is universally used only in connection with the *current*, we adopt another term where reference is intended to the E.M.F.

This plane of cessation of force, therefore, may be regarded as a plane that is invariably normal, or at right angles, to the lines of magnetism traversing the core. It is thus the plane in which the coils, as they successively arrive into it, neither include nor exclude lines of magnetism, and consequently, *cease to generate*, or are not generating any E.M.F.—though they may be *charged* with the full voltage of the machine (*see* p. 9). The instant they rotate beyond, they commence generating the reverse E.M.F., whose function is to impel the current coursing in the other half of the winding (*see* Chap. I).

In the diagrams, Figs. 105 and 106, this plane, lettered C F, is shown at 90° with a line $y\,y$. This latter line represents the centre plane of the induction lines through the core, and passing through the ultimate poles of the armature, represents its *ultimate polarity*. Another line, $x\,x$, represents the centre plane of the field. The angle θ between them thus indicates the "distortion of the field" alluded to in Chap. I. (p. 13).

Now, it is evident that as the plane C F is invariably normal to $y\,y$, if any cause affects the inclination of the latter plane, then C F must be similarly affected and made to oscillate. Thus, as was explained in Chap. I. above mentioned (pp. 12 and 13), the *ultimate* polarity of the armature is a compromise between its own *self-polarisation* and the polarity of the field; and in practice the latter is made much stronger than the former, so that a line ($y\,y$) through the ultimate poles will only form a small angle (θ) with the centre line ($x\,x$) of the field. But it has to be observed that the *self-polarity* of the armature, depending on the circulation round it of its own current, can of necessity possess its two poles only at the two regions where the current respectively *enters* and *leaves* the winding. In other words, inasmuch as the current can only flow in and flow out where the brushes permit, the armature *self-polarity* is directly governed by, and must *follow* the brushes. Therefore, if the armature self-polarity is swayed by a movement of the brushes, the *ultimate* polarity must be proportionately affected, though of course in a smaller degree. Consequently, C F will be affected also, equally with *y y*. A comparison between Figs. 105 and 106 will reveal this change of position of C F, concomitant with the shifting of the brushes. In a strong field the difference between the C F and M M planes may be small, as shown. But with a weak field, to be discussed in a later Chapter (XXIII.), a considerable angle may exist between the two planes, with much lead to the brushes.

We thus find that whereas the plane of commutation (1) moves directly with the brushes, and the other four planes were absolutely fixed, and the two through the commutator to be determined by experiment, this plane of cessation of force occupies an intermediate position in this respect, and is what we may describe as semi-fixed.

It is to be noted, however, that *for any given position of the brushes*, this C F plane is also the *then* plane of maximum and minimum potential for the armature. For as the coils at the positive end of each half of the winding occupy positions of successively smaller angular propinquity to this plane, whether approaching it, or receding therefrom (*see* p. 11, upper paragraph), so they generate less, but become more fully charged with potential; and so, when actually in the plane, though generating nothing, they are charged to a maximum. At the negative end of the winding, of course, the inverse holds good; and the coils in the plane are not only generating no E.M.F., but are also charged with a minimum potential.

The normally fixed M M plane (5) may thus be further understood to be that plane which is occupied by the movable

C F plane, when the E.M.F. of the coil or section of winding in the latter is the maximum E.M.F. of the machine. As reflection will make clear, this also can only be when the Cn P plane, movable with the brushes, is coincident with the C F plane. Thus, when the brushes are at the points of maximum and minimum potential on the commutator, the three planes, C F, Cn P, and M M, are one. In other words, the brushes only gather the maximum E.M.F. of the machine when the planes of the coils in series with them are normal to the main flow of induction through the armature, which can only occur when the brushes are in one particular position.

Now we have stated that when the brushes are in the plane of maximum E.M.F., that is, the M′ M′ plane of the commutator, they will spark. When the brushes are put forward to the non-sparking position, the C F plane, ceasing to coincide with the M M plane, will occupy an intermediate position, as shown in the diagrams. A fall of potential difference between the brushes will result as stated; and it will be observed that the current in the coils lying between the C F and the Cn P planes, in order to reach the brushes, will have to flow against a *reverse*, or counter E.M.F. For the *commutation of the current* in the Cn P plane is taking place *in advance of* the *reversal of the electromotive force* in the C F plane.

With regard, however, to the sixth plane once more, as this is necessarily normal to *y y*, it is palpable that *any* causes, besides, or additional to, that of moving the brushes, that may alter the inclination of *y y*, and vary the angle θ, will produce a corresponding oscillation of the C F plane. Such other causes, however, may likewise affect all the normally fixed planes. But these we must leave for subsequent consideration.

CHAPTER XVII.

SPARKING AT COMMUTATORS.—ELEMENTARY CONSIDERATION OF THE BRUSH.

HAVING thus far ordered and distinguished between these various planes, we may now commence more closely to consider their application to the question of sparking at the brushes of a dynamo. Fig. 109, herewith, represents the top of a commutator; B is the brush resting on two segments *r* and *s*, and the letters *d d* and *c c* show the coils bringing up the current from either side of the armature, as indicated by the arrowheads.

Now, normally, the current, in order to get from series *c c* to series *d d*, or *vice versâ*, would flow through the coil *b*, which we have shown thicker than the others. But this coil is for the moment "short-circuited" by the brush: for a current could pass between *c c* and *d d* through *r* and *s* and the point of the brush, which would be a path offering much less resistance than the passage through the coil in question. This latter coil may consequently seem to be idle. So far from this being the case, however, it is the behaviour of this coil that is chiefly concerned in the question of sparking at commutators. For it has but just belonged to the series *d d* and is about to join the series *c c*, wherein the current is running in the contrary direction. Hence, it is just in or about this position in relation to the brush that a reversal of current takes place within the coil *b*. Thus the plane wherein this coil lies at that instant is termed the "plane of commutation," or plane of change.

Now, in Chapters XIV. and XV., when discussing the subject of self-induction, we pointed out that that was purely a *magnetic* effect; and that the changes of magnetism were the causes of the electrical effects. Thus it is here: for this coil has a

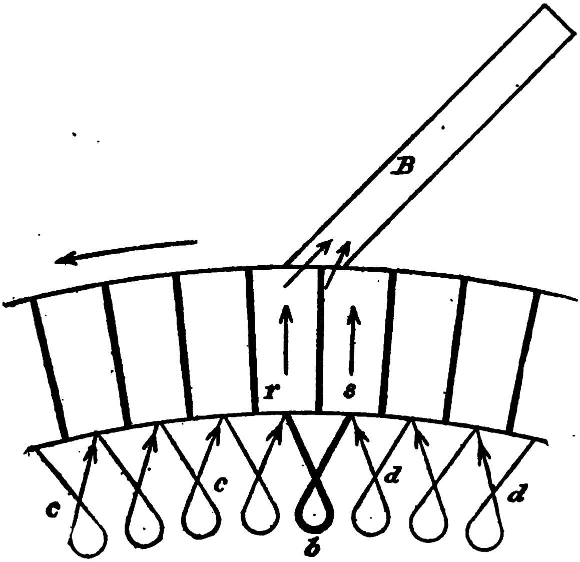


Fig. 109.—Diagram illustrating Elementary Theory of the Brush.

polarity of its own, which is enhanced by the iron of the armature core within it. Hence, it is in reversing this polarity that energy is lost. This reversal of polarity may not at first seem obvious, inasmuch as the polarity of the iron within the coil is not actually reversed at all at that moment. But the polarization of the iron of the core is the sum total effect of all the polarizing influences brought to bear on it. The coil in question exercises its share in these influences, and it is thus this share that has to be reversed.

It may be noted further that the coil *b*, though short-circuited by the brush, is still in series with the *c c* and *d d* coils. Or should there be any tendency for an independent current to circulate within *b*, it is free to do so; and, the resistance of the one coil, or section of winding, being comparatively small, a small electromotive force may thus create within *b* a large "short-circuit" current.

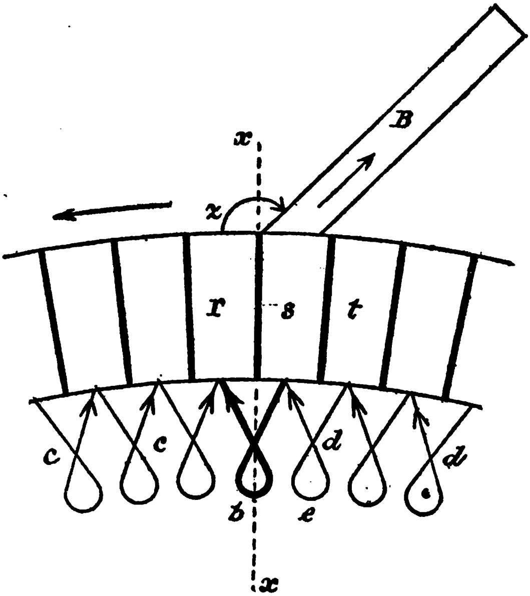


FIG. 110.—Diagram illustrating Elementary Theory of a Spark at the Brush.

We may now, however, transfer our attention to Fig. 110. It will be observed here that the segment *r* is shown just leaving the point of the brush—just the time, in fact, for a spark to occur between *r* and B if the conditions admit. Now, the coil *b* has hitherto had the *dd* current direction and polarity within it, as indicated by the arrowhead. But the *c c* current, immediately on *r* receding from the brush, has to flow through *b* in order to reach B. It is evident, however, that if the coil *b* offers any sort of resistance to the passage of the *c c* current, with an opposing current or otherwise, and supposing for the moment that this resistance be absolute, so that no *c c* current can traverse *b* at all, then the break of contact between the segment *r* and the brush will be precisely similar to the opening of the gap *g* in Fig. 101. For the coil *b* offering no path, the current is broken. Hence, a spark due to the self-induction of the *c c* coils, will flash across from the segment *r* to the brush, as indicated by the small curved arrow *z*. But the parting of this segment *r* and the brush is furthermore to be likened to the opening of a switch; for the conditions assumed are precisely similar.

In discussing this latter, we showed that the flash then seen was a compound effect, being composed of a self-induction disruptive spark, as just alluded to, immediately followed by a momentary arc, assuming a current of not less than five or ten amperes, and an E.M.F. not exceeding some few hundred volts, which are ordinary conditions. We mentioned, also, the exceedingly small space of time occupied by the precursory spark. Now, however rapid in practice the peripheral velocity of the commutator may be, the flash at the brush will be such that by far the larger proportion of the time occupied by it will be taken up by the arc. Further, when discussing the arc, we showed that the electrodes were consumed by it, the positive at twice the rate of the negative. Hence we now perceive that in the flash between the segment *r* and the brush, the arcing will preponderate. Both will be burnt; but the segment here, being positive, will be burnt the most.

If, however, the resistance of the coil *b* (that is, any impeding cause or causes, whether due to the simple resistance of the coil itself, or that, with adverse inductive influences added) is only partial, the compound flash will be reduced in strength. Some of the current passing through the coil *b*, there will not be so much to break at the brush point, and the flash will be what we may term a "shunt" flash. This is illustrated in Fig. 101 (page 140): for if on the gap *g* being opened, some of the current could still pass by way of a small lead, *c c*, shown

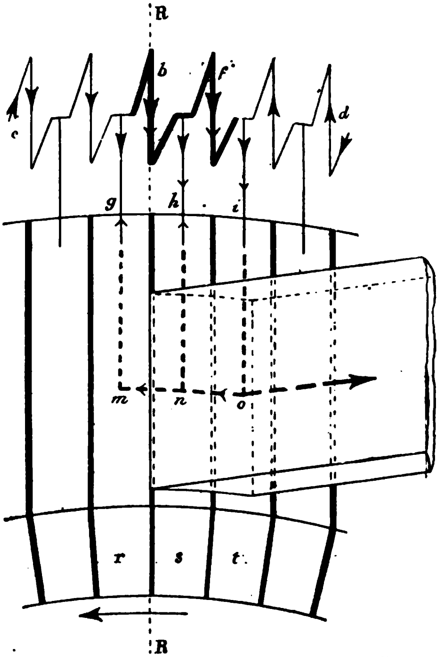


FIG. 111.—Non-Sparking Position. Short-Circuited Coil *b* in Plane of Requisite Reversal.

dotted, it is evident that the reduction of the magnetic induction in the core of the coil would not be so great as though there were no such other path. Hence the self-induction E.M.F. at the positive end of the gap will be diminished, and consequently the violence and length of the initial disruptive spark and the magnitude of the subsequent momentary arc. This "shunt" effect, however, as we shall find later, would only occur close to the non-sparking position on the commutator.

We may now turn our attention to Fig. 111, showing the conditions necessary for sparklessness. As may be perceived, this represents the top of a commutator, three of whose segments are lettered respectively *r*, *s*, and *t*; the armature coils are represented between *c* and *d*, two of them being lettered *b* and *f*; and three of the lugs are lettered *g*, *h*, and *i*. The "neutral plane" of the commutator is assumed coincident with the "plane of requisite reversal" of the armature, and these are jointly indicated by the line R R. The brush is shown thicker than that in the last diagram, and here covers more than one segment. Two of the coils, *b* and *f*, are short-circuited by the brush, and so are shown heavier; and the short-circuits through the brush point are indicated by the thick dotted lines *m n o*. The large arrowheads show the main current arriving from the two halves of the armature winding, *c* and *d*, and the small arrowheads represent the short-circuit currents. It will be noted that the *b* and *f* coils have just left the series *d*, and are passing into the series *c*. Having passed the C F plane, the *d* current that was circulating within them has first been stopped as they each arrived into the plane of commutation, and then a reverse short-circuit current has been set up within them by the *c* electromotive force. At the moment shown, this short-circuit, or as for brevity we may term it, the s.-c. current, in coil *b*, exactly equals the *c* current. Meeting each other in the lug *g*, these two currents neutralise each other: hence there is no current flowing either way between the brush and the receding segment *r*. There thus being no current to break at the recession, there is no sparking; and the coil *b* is just precisely in the "plane of requisite reversal" represented by the line R R. The positive brush being here shown, for a representation of the non-sparking conditions at the negative brush, it is simply necessary to reverse all the arrowheads.

CHAPTER XVIII.

SPARKING AT COMMUTATORS.—THE SHORT-CIRCUITS AND CURRENTS.

It is now our purpose more narrowly to investigate the subject of the short-circuits under the brushes; for without this, no thorough understanding of the theory of the sparking at commutators is to be attained.

On reference once more to Fig. 111 in our last chapter, it will be observed that in consequence of the thickness of the brush, two coils were short-circuited, as was mentioned. The question, however, arises, as to how these two coils will affect each other in respect of the reverse, or short-circuit, current that will be generated within them. In this connection we may direct our attention to Figs. 112 and 113. We here find in each diagram two circuits P P and Q Q, having a common conductor $x\,y$. But in the former the two currents issuing from generators w and v *augment* each other in $x\,y$, while in the latter they *oppose* each other. It is thus this latter case which we may now consider. For if the two currents are equal, there will be no current in $x\,y$; while if they are unequal, $x\,y$ will carry the difference. This, in fact, illustrates the essence of what is termed the "three-wire system," $x\,y$ representing the "neutral" main. It will be noted further that the P current leaving *w*, and the Q current leaving *v*, checking each other in *x y*, they each continue in the other's circuit. More accurately, it may now be said that there is only *one* circuit with the two generators in series; and, in fact, the two currents may be said to be *assimilated*. None the less, if the Q current be, say, 250 amperes, and the P current, say, 200, the Q current will split at *x*, 50 passing down to *y*, and 200 only continuing by *w*. Uniting at *y*, 250 will enter the negative at *v*. Thus, though *assimilated*, the two currents, taken separately, retain their original values. This does not apply in the case of Fig. 112. For provided *x y* is large enough to carry both currents, they will wholly take that path, and there will be nothing approaching the nature of assimilation. It may be noted that in Fig. 113 the generators in series cannot each augment the current of the other in the outer circuit *w y v x*, because their inherent resistances are also in series.

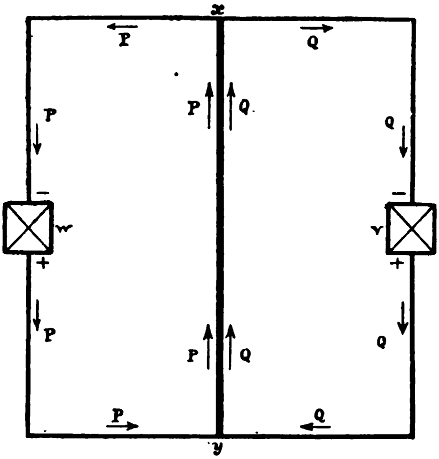


Fig. 112.—Diagram showing Two Circuits with a Conductor common to both, in which the currents are *united*—illustrative of *augmentation*.

Now in Fig. 111 there were two short-circuits *b h n m g* and *f i o n h*, of which the coils *b* and *f* formed respectively a generator in each. Inspection will make it clear that these two circuits are similar to those in Fig. 113, and that *h n* is a conductor common to them both, in which their two currents are *opposed*. We hence perceive that the two short-circuit currents are *assimilated* with each other, and that *h n* will merely carry their difference; and in so far as the coils *b* and *f* may be regarded as in series with each other in the circuit *b f i o n m g*, their internal resistances will of course be in series also. Hence, whatever current each may generate, these do not reinforce each other, and each current retains its own value within its own circuit.

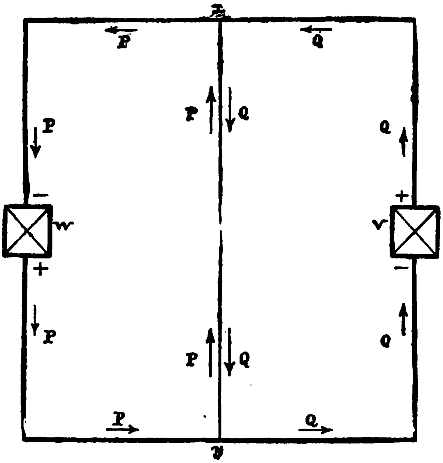


FIG. 113.—Diagram showing Two Circuits with a Conductor common to both, in which the currents are *opposed*—illustrative of *assimilation*.

We may now direct our attention to Fig. 114. This may be recognised as a combined diagrammatic representation of Figs. 111, 112 and 113. The segments *r*, *s* and *t*, the lugs *g*, *h* and *i*, and the coils *b* and *f*, together with the brush shown dotted, may be observed. On either side the two series of coils *v* and *w* represent the two halves of the armature winding. It will be noted that there are here *four* distinct circuits, P P, Q Q, P′P′, and Q′Q′, each with a generator, *w*, *b*, *v* and *f* respectively. These do not include the outer circuit, which is comprised within the line shown partly dotted between *n* and *y*. The arrowheads indicate currents, that is, the currents the four electromotive forces *tend to maintain*; for as we shall see, the *actual* currents will depend on conditions that may be assumed. Of these currents, the P P and P′P′ being the main armature currents, may be regarded as invariable both as to direction and quantity; while the Q Q and Q′Q′ currents, contrariwise, will be variable, according as to whether the brush may have too much positive or negative lead. The negative brush is at *y*, whence the current from the outer

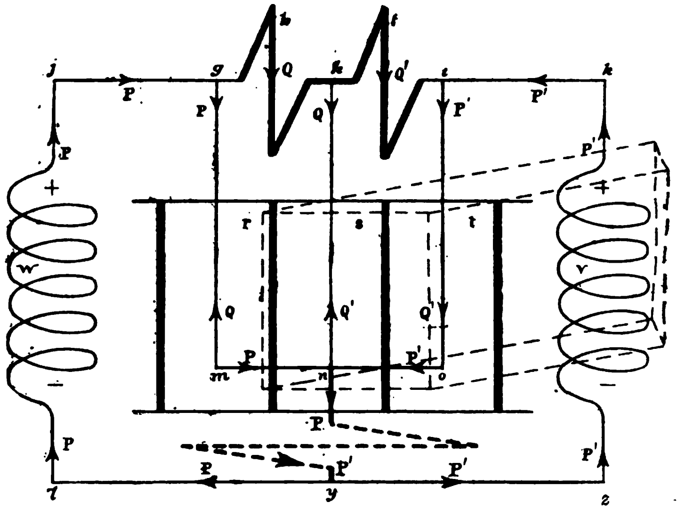


Fig. 114.—Diagram illustrating Theory of Short Circuits in a Commutator.

circuit divides right and left through the two halves of the armature winding, as indicated.

Now a development of Ohm's law, namely, E.M.F. = current × resistance, is that a current at a given potential having two or more paths open to it, will split itself among these in inverse proportion to their several resistances. Thus the path offering the least resistance will carry the most current, and *vice versâ*. It will now be noted on reference to the diagram, that in the course of their circulation the P main current needs to get from *g* to *y*, and similarly, the P′ main current from *i* to *y*. The combination of the effect of Ohm's law on the one hand, and the interposed effect of the short-circuit currents on the other hand, thus forms a subject which we may now consider.

The P current arriving at *g* has three paths before it by which to reach *y*, namely, *g m n*, *g b h n* and *g b f i o n*. Similiarly, the P′ current has three paths before it, starting from *i*. It will be obvious, however, that the resistance of the lugs *g* and *i*, will be considerably less than that of the coils *b* and *f*. Hence, according to Ohm's law as above enunciated, by far the larger proportion of the P current will travel by *g m n*; a very small amount may go through *b h n*, while the flow of P through *f* will be quite fractional. For the same reason most of the P′ current will flow through *i o n*, and small quantities only through *f* and *b*. But this, it will be understood, is only the *normal* flow of the P and P′ currents, disregarding the effect of the Q and Q′ short-circuit currents. At these latter we may now glance.

The short-circuit currents being variable, may be assumed to flow in either direction through *b* and *f*, and to be equal to, greater, or less, than the P and P′ currents. A direction parallel with P is thus assumed in the diagram, as indicated by the arrowheads. It will now be observed, that the Q and Q′ circuits having a common or "neutral" conductor *h n*, like *x y* in

Fig. 113, if the two currents are equal, *h n* will carry no current, or if they are unequal, it will carry the difference. In actual practice the latter would be the case, and in this instance, where an amount of forward lead is assumed, *b* would generate a higher E.M.F. than *f*, and so, the resistance being similar, would impel a larger current. Thus the lug *h* will simply carry a small inflow of Q current, equal to the difference between Q and Q′; and these two currents will be what we have termed "assimilated," each flowing in the other's circuit, but retaining its original value in its own circuit. Further, it is to be observed that there will be a *normal outflow* of Q current in the lug *g*, and a *normal inflow* of Q′ current in the lug *i*.

We may now return to the main P and P′ currents. It will simplify matters if, ignoring the small quantities of these currents that normally run in *b* and *f*, we assume that they flow wholly through the lugs *g* and *i* respectively. Hence whereas *h n* was a neutral between Q and Q′, it is now to be observed that *g m n* is similarly a common path for the P and Q currents, wherein they oppose each other. Thus we here perceive finally that the *actual* current in *g m n* will be the difference, if any, between P and Q, whichever may predominate. If they are equal, and the segment *r* just leaving the brush as depicted, this will be the condition for no sparking as already touched on, as there will be no current to be broken at the moment of recession. But the result now is that as the P current baulks the Q current in *g m*, it becomes assimilated with it, precisely as Q and Q′ are assimilated. The P, Q, and Q′ currents become in fact all three assimilated, though each retains its original value in its own circuit apart. Thus the great point to be noted here, is that the P current arriving at *g*, does *not augment* the Q current in *b*, as at first might be supposed. For baulking the latter in *g m n* it baulks its entire flow throughout its circuit (Q Q Q), and assimilation takes place instead, as explained.

Now, however, to consider the P′ current at *i*, we find *i o n* also forms a path common to the Q′ and P′ circuits. But here the two currents do *not oppose* each other, as did P and Q in *g m n*. Consequently they in this case *augment* each other, and both flow together in one large current through *i o n*, always provided that the lug *i* is of sufficient section to carry the increase of current without becoming heated, and thereby offering an increased resistance.

It will be advantageous, however, if we assume cases. Thus suppose P and Q be equal, each being 200 amperes. P′ would be 200 also, making 400 amperes for the outer circuit comprised in *n y*. Q′ may be, say, 80 amperes. There will thus be no current whatever in *g m n*, and only the difference between Q and $Q' = 200 - 80 = 120$ amperes flowing inwards in the lug *h*. The 200 P will be assimilated with the Q and Q′ currents; and the Q′ current of 80 is flowing down lug *i*. Thus the P current of 200 amperes, assimilated within the Q and Q′ circuits, may be said to divide at *h*, 120 going down *h n*, and the remaining 80 travelling by *f i o n*. But the P′ 200 amperes are running unimpeded in *i o n*. Thus, in this latter path, there will be a total current of 200 P′ + 80 assimilated P, Q and $Q' = 280$ amperes. Being joined at *n* by the 120 amperes down *h n*, this thus makes a total of 400 in *n y*; while there is no flow in *n m g*.

From the above, it may hence be perceived, that in the non-sparking position, the effect of the short-circuits is to divert the flow of the current from the point of the brush towards the heel. It should be noted, however, that this is the effect of the *electromotive forces* of the short-circuited coils. As prime causes these remain unaltered, while their effects, as in the case of the current in *g m n*, may be entirely eliminated.

If, however, while P and P′ remain each 200, we assume Q to be 100, and Q′ say 10, we shall find $P - Q = 200 - 100 = 100$ amperes of the P current flowing through *g m n*. In lug *h*

$Q - Q' = 90$ will inflow; while the total flow down the lug *i* will merely be 10 assimilated P, Q, and $Q' + 200\ P' = 210$ amperes. At *n* there will thus unite, 100 from *g m*, 90 down *h n*, and the 210 down *i o*, making 400 again in *n y*. But this current of 100 in *m n* would be broken at the recession of segment *r* from the brush; and there would occur, in fact, what we have termed "shunt" sparking (p. 165), as only *part* of the P current is broken, the remainder being assimilated with Q. The sparking will result from the self-induction of the half of the armature winding represented by *w*, as described in connection with Fig. 101 and the dotted line *c c* therein. This condition for shunt sparking is brought about, it will be observed, by the near approach of the brush point to the N P plane, so that the Q current in *b* is running in the same direction that P would take through *b*; but the brush is not far enough forward for Q to equal P, as would be the case were *b* in the R R plane. It will thus be seen that this shunt effect occurs just *behind* the neutral plane, and there only.

CHAPTER XIX.

SPARKING AT COMMUTATORS.—THE SHORT-CIRCUITS AND POTENTIALS.

In our last chapter we dealt almost solely with the *currents* of the short-circuits. It is now, however, the potentials that we propose to discuss. For a point to be noted in connection with the four adjoining circuits represented in Fig. 114, is that whereas to suit the external resistance comprised in $n\,y$ the E.M.F. of the P and P′ main currents needs to be high, say 500 volts ; in the case of the Q and Q′ circuits, on the other hand, wherein the resistance is extremely small, the E.M.F. will be very low to produce the same current. Thus the latter E.M.F. may be only a fraction of one volt. This minute voltage may thus appear of no account in contention with that of the main currents: while, on the other hand, the question might be as to whether, as a matter of fact, this small electromotive force of the short-circuits *would* in any way affect that of the main current.

In Fig. 115 herewith are two circuits, P P P and Q Q Q, having a common conductor $x\,y$, in which the currents oppose each other, as in previous diagrams. The letters w and v indicate the respective generators. It is to be noted, however, that the P circuit is represented as having a resistance of 5 ohms, while the Q circuit has a resistance of only ·05 ohm.

Thus to get the same current in each circuit, here shown 200 amperes, we find needed a potential difference between the terminals of 200 × 5 = 1,000 volts in the P circuit, but only 200 × ·05 = 10 volts in the Q circuit.

Further observations, however, require now to be made. First, we note that the generators *w* and *v* being in series with each other by way of *a b*, without resistance (neglecting the resistance of the conductors), their electromotive forces will accumulate. Thus the negative terminal of *v* becomes raised to 1,000 volts, the same as the positive of *w*; and the positive of *v*, having the extra 10 added, becomes raised to 1,010 volts. Secondly, we note that *x y* being assumed without resistance, this conductor is at 1,000 volts throughout and at both ends.

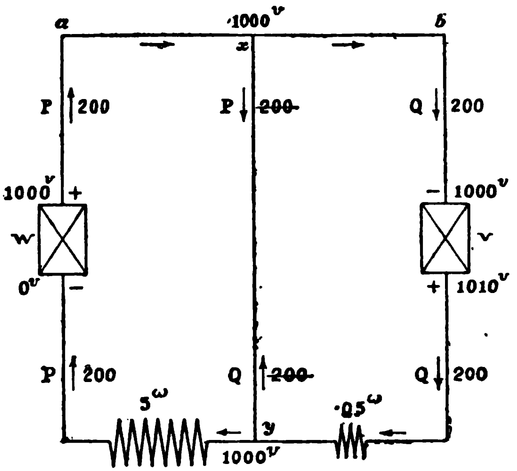
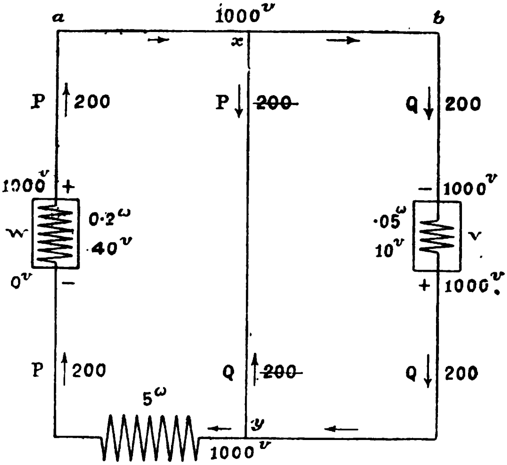


FIG. 115.—Two Circuits of Different Potential with currents assimilated, both having resistance exterior to generators.

It will now be observed that as there is a difference of 10 volts between the *v* positive and *y*, this 10 volts will impel a current of 200 amperes through the ·05 ohm resistance.

This current would now naturally, by Ohm's law, flow through *y x*, as offering the easiest path to its negative at *v* once more. The P current arriving at *x*, however, would also, by the same law, flow in the opposite direction entirely through *x y*, inasmuch as this would be a path of *no* resistance as compared with the resistance in the Q circuit. Hence, assimilation of the currents will take place: and no current will flow in *x y*, as indicated in the diagram by the opposing P and Q arrows, and the numbers struck out by lines drawn through. It will hence be noted, that as here arranged, the voltage of the P circuit is not affected by that of the Q circuit.



116.—Two Circuits of Different Potential with Currents assimilated, with no exterior lesser resistance.

If, however, the terminals of the generators be reversed so that the current runs in the opposite direction, there will at once be an alteration in various respects. The "neutral" will drop to only 10 volts, the same as *v*; and the only high potential portion of the circuits would be between *w* and the 5 ohm resistance, where there would be a pressure of 1,010 volts. But in the diagram, the conductor *x y* lies between the *w* positive and the 5 ohm resistance; and all parts lying between the *w* positive and this high resistance, including connected parts such as the whole of the Q circuit, will become charged with the high voltage.

We may now, however, turn to Fig. 116. The difference between this and the last diagram will be observed to be that the 0·05 ohm resistance of the Q circuit is here represented as being the internal resistance of the generator *v* itself. In Fig. 115 we neglected the internal resistances of the generators. If, however, we assume an internal resistance for *w*, in the case before us, of, say, 0·2 ohm, this, in order to admit of a current of 200 amperes, will need a pressure of 0·2 × 200 = 40 volts. Thus the total E.M.F. of *w* will be 1 040 volts; but the odd 40 being spent internally there will be only the 1,000 for external use.*

A further peculiarity of the external voltage, however, is that it will depend for its existence on the resistance of the outer circuit. If the outer resistance be diminished while the internal resistance is unaltered, the total resistance of the circuit is lessened. Consequently, a larger current will flow; and a greater proportion of the total E.M.F. (assuming this to be unaltered) will be spent in forcing the increased current through the internal resistance; and a smaller potential difference will appear between the terminals externally. Thus if the 5 ohms of the P circuit be reduced to 1 ohm, while the internal resistance of *w*, as previously assumed, is 0·2 ohm, the total resistance of the P circuit will become 1·2 ohms. With the total E.M.F. of 1,040 volts, we find the current will now be

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* This and succeeding points may be found dealt with mathematically and geometrically in Prof. Silvanus P. Thompson's "Dynamo-Electric Machinery," pp. 226 to 230, fourth edition.

1,040 ÷ 1·2 = 866·7 amperes. But the E.M.F. will be re-distributed; and we find that the amount used internally will be 866·7 × 0·2 = 173·3 volts as compared with the previous 40 only; while externally the potential difference will be 866·7 × 1 = 866·7 volts instead of 1,000; and the total E.M.F. is summed up thus, 866·7 + 173·3 = 1,040 volts as before.

It will thus now be obvious, that if the resistance is wholly internal, and there is *no* external resistance, there will likewise be *no* external voltage; and the E.M.F. will be spent entirely in overcoming the internal resistance. This is the case assumed with the Q circuit in Fig. 116. The resistance here being wholly internal, there is no potential difference externally between the terminals.

Similarly, however, to the conditions depicted in the previous diagram, the two generators are in series; and *x y* and the Q circuit lie between the *w* positive and the 5 ohm resistance. Consequently these parts are all charged at the 1,000 volts, included both the terminals at *v*, now without potential difference between them; and the E.M.F. of the P circuit is unaffected by the E.M.F. of the other circuit. If the E.M.F. of the *v* generator should rise or fall, this would merely cause the Q current to fluctuate; and there would still be no potential difference between the *v* terminals externally.

We may thus return once more to the diagram Fig. 114. The case of the four circuits there is analogous to the case of the circuits in Fig. 116. For the Q and Q′ generators have likewise only their own internal resistances and self-induction to overcome, so far as the short-circuits are concerned, and assuming the resistance of the remainder of the short-circuits to be so small as to be negligible; while the P and P′ generators (*w* and *v*) have the resistance of the outer circuit in *n y* to contend with. We may assume similarly that *v* and *w* each generates a total E.M.F. of 1,040 volts, of which 40 are spent in forcing the current of say 200 amperes through its own resistance, leaving 1,000 volts to rise at *g* and *i*, for which the negative will be at *y*. It will then be seen that the Q and Q′ circuits, lying between *g* and *i*, and the point *n* where the external resistance commences, are at 1,000 volts throughout; and that however much the E.M.F. of the coils *b* and *f* may vary, there will yet, in respect of the short-circuits, be no potential difference between the points *g*, *h* and *i*, assuming the paths *h n*, and *i o n m g*, to be without resistance.

The actual potential difference between the points *g*, *h* and *i* is entirely dependent on the relations between the E.M.F. of the armature winding, as represented jointly by all the coils, *w*, *b*, *f* and *v*, and the *exterior resistance* in *n y*. In the diagram, the brush is assumed forward: therefore, the point of highest potential will be behind the brush, where the sum total voltage of *w*, *b* and *f*, and perhaps some more coils toward *k*, will have *accumulated*. Consequently, the point *i* will have a higher potential than *h*, and *h* than *g*. But this *accumulation* of voltage is entirely due to the *exterior resistance*. For we know that if the latter be eliminated from the outer circuit, supposing it possible, an enormous current would flow, and there would be no potential difference between the positive and negative brushes, showing that the E.M.F. of the successive coils of the armature had *ceased to accumulate*. Hence in the diagram there would then be no accumulation of the voltage of *w*, *b* and *f*, and so the points *g*, *h* and *i* would all have the same potential. Yet the coils would be *still generating* E.M.F. (assuming other conditions unaltered); but this would be used now internally only, in impelling the current against their own interior resistances. It is thus that the short-circuit currents will continue to circulate, independently of what changes may be wrought on the potential at *g*, *h* and *i* by exterior influences; and of themselves alone, these Q and Q′ generators would cause no potential difference between these three points, except such as might be due to the extremely slight resistance of the short-circuit paths, *h n* and *i o n m g*.

It must be noted, finally, that the energy required to commutate, and to requisitely reverse the current in the short-circuited coils, is a deduction from the efficiency of the machine. This is evidenced by the fact that the non-sparking points are not in the M′M′ plane, but ahead of it. The product of the potential difference between the M′M′ and N P planes, and the short-circuit current, will indicate the power lost in bringing the current in the short-circuited coils to a state of requisite reversal.

CHAPTER XX.

SPARKING AT COMMUTATORS.—EFFECTS OF MISPLACEMENT OF BRUSHES.

We may now consider cases where sparking takes place. The most simple will be those when the brushes are shifted too far forward or backward: or, again, which amounts to the same thing, if the brushes are at their right places, a cause of sparking may be the oscillation of the neutral plane. For the present, however, we may confine our remarks to the simple displacement of the brushes.

Fig. 117 herewith shows an armature revolving in a field, and a commutator, together with brushes. These latter are shown in positions A and B too far back, and at C and D too far forward. We now propose to deal with these four positions in detail, and to consider the nature of the sparking that occurs in each. Figs. 118 to 121 are thus four diagrams showing each brush separately. For the better elucidation of the subject, a total current output for the machine of 400 amperes is assumed, as indicated in the diagrams. It is necessary, however, to note that in these diagrams the conditions represented are *those that are broken* by, and so are *not* the results of, the recession of the segments *r* from the brushes. Short-circuit (or s.-c.) currents of 500 and 450 amperes are assumed in the coils *b* and *f*, according as the one or the other is in the better position for generating E.M.F. The main armature currents *c* and *d*, of 200 amperes each, are indicated by the large arrowheads, and the s.-c. currents by the small arrowheads, as before. The double arrowheads represent *resultant* currents, whether by difference or addition; and it will be noted that the two amounts which together produce a resultant, are struck

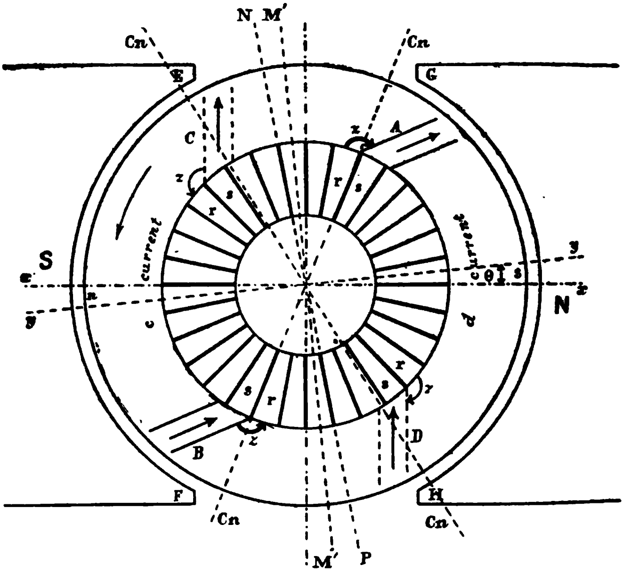

FIG. 117.—Diagram showing Brushes with too much Positive or Negative Lead.

out by a line drawn through, in a manner similar to that adopted in Fig. 116.

It will now be seen, on reference to Figs. 117 and 118, that the brush A being on the *d* side of the commutator, up to the moment of the recession of segment *r*, there has been nothing whatever to reverse the electromotive force of the coils *b* and *f*. Hence their s.-c. currents will circulate in the same direction as the *d* current. As indicated by the large arrowheads, the latter still flows in these coils; though this is to anticipate. The two s.-c. currents, as explained in connection with Figs. 113 and 114, will become assimilated with each other, their difference only, 50 amperes, entering by lug *h*: there will be a *normal* outflow of 500 s.-c. amperes through lug *i*, and a *normal* inflow of 450 s.-c. amperes by lug *g*; and it will be noted that in this case the s.-c. currents are traversing the coils *b* and *f* in the opposite direction to that shown in Fig. 114. We may now consider the *d* and *c* main currents, and may take the former first. This would naturally attempt an inflow

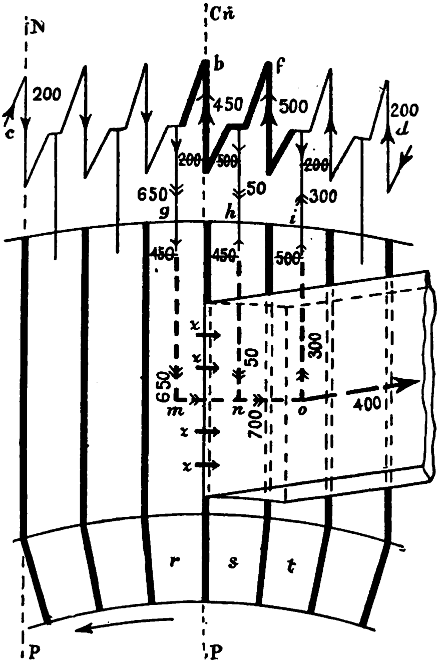

FIG. 118.—Positive Brush too far back. Heavy Forward Sparking. (Position A in Fig. 117.)

through lug *i*. It is, however, met there by the normal *j* s.-c. 500 outflow. The resultant 300 outflow is thus what remains. But the *whole f* s.-c. 500 is reduced by this same act. The 200 *d*, blocked back in *i*, takes the place of the missing 200 in *f*, or, in other words, becomes *assimilated* in that coil; and the *b* and *f* s.-c. currents being already assimilated, it becomes assimilated with both these currents, like the P and Q and Q′ currents in Fig. 114.

Reverting to the *c* main current, we find this inflows through lug *g* in the same direction as the *b* current. These thus *augment* each other, forming a united or resultant current of 650 amperes. To analyse this amount accurately, we observe that it is composed of 200 *c*, plus the *d* assimilated with the 450 s.-c. current. At the point *n* this amount is further augmented by the inflowing 50 down *h*, thus making a total of 700 from *n* to *o*. Of this total, 400 go up the brush, being the sum of the *c* and *d* currents, while the remaining 300 form the 300 s.-c. current in lug *i*. We thus find the cycle completed.

Now, from the above we note that the actual current that is broken is *more than* the main output, being 650 amperes instead of only the normal 400. Furthermore, we observe that the spark which will occur at the recession will be due to the self-induction of both the *c* and *d* series of coils *plus* the additional effect produced by the short circuits—that is, to the self-induction of the whole of the armature-winding. Hence the sparking will be heavy, and will be in the same direction as the main current, as indicated by the thick arrows *z z*. A large current, moreover, being broken, there will be considerable burning with the arcs, especially of the segment *r*, which is here the positive electrode.

Fig. 119 may now engage our attention. This represents in detail the brush in position C (Fig. 117), where it is shifted too far forward of the N P plane, which latter is indicated in both diagrams. It will first be noted that the coil *b* here carries the

500 s.-c. current instead of *f*, as in the last case. A resultant 50 amperes of the *b* s.-c. enters by lug *h*; and it will be perceived that the s.-c. currents here are traversing the *b* and *f* coils in the *same* direction as in Fig. 114. There is thus a normal 450 assimilated s.-c. current entering through *i*, and a

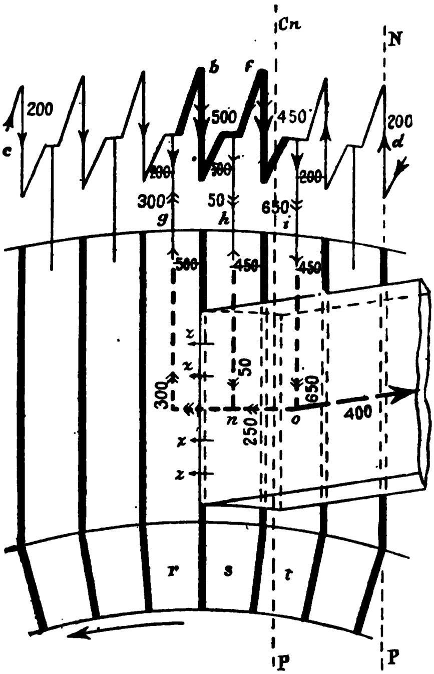

FIG. 119.—Positive Brush too far forward. Light Back Sparking. (Position C in Fig. 117.)

normal 500 s.-c. current flowing out through lug *g*. The *c* main current, arriving at *g*, is blocked by the outflowing *b* s.-c. 500, and becomes assimilated with the latter in the coils *b* and *f* instead, in the same manner as the *d* current in the previous case. We thus find the 450 entering by lug *i* to be composed of the *c*, and the s.-c. currents assimilated. To this latter is now added the 200 *d* main current, making a total resultant current of 650 amperes entering by this lug. Arriving at *o*, however, 400 amperes split off to ascend the brush, thus leaving only 250 to continue to *n*. At this latter point, this current is joined by the 50 *b* s.-c., making the 300 out-flowing through *g*. Thus again is the cycle completed.

Now here there are various points to be noted. First, it is *not the main d and c* currents that are broken, for these have both a free entry into the brush through its *heel* instead of the point; and the heel continually *makes* contact with the segments, one after the other, instead of breaking contact, as compared with the case of the brush at A. It is thus the coils *behind* the brush that are reversed, and not those just leaving the point. The effect will then be that the momentary check due to the self-induction of the coil *f* will cause the reduction of the 650 in lug *i* to 50, as it arrives at position *h*, to be *gradual* instead of sudden. We shall return to this, however, in connection with the line CnP. The point to which we would now draw attention is thus, secondly, that it is only a *short-circuit current* of 300 amperes that is broken at the recession; and further, that this is running in the *opposite direction to the main current* flowing up through the brush. We have here, hence, what has been termed "back-sparking," as indicated by the arrows *z z* in Figs. 117 and 119. Being due, moreover, to the self-induction of the coils *b* and *f* only, the sparking is slight; while the current broken being but 300 instead of 400, or 650 as in the last case, the arcing is not so heavy. The brush, however, being positive, will incur most of the burning.

We now come to Fig. 120. This represents the lower brush in position B. As it would have been confusing to invert the diagram to make it accord with the actual position of the brush on the commutator, we do not do so, and merely indicate the main current *entering* by the brush instead of leaving. It will be seen here that the brush is too far back, like brush A; while of the two short-circuited coils, *f* carries the 500 amperes, being nearer the plane *y y*. The first point that may be noted is that the difference between the *b* and *f* s.-c. currents, that is, the resultant 50, instead of flowing inwards in the lug *h*, is here flowing outwards. A normal 450 s.-c. current outflows through lug *g*; and a normal 500 s.-c. current enters by *i*. But now the main current from the outer circuit arrives by the brush at *o*. Its natural course being to split and send

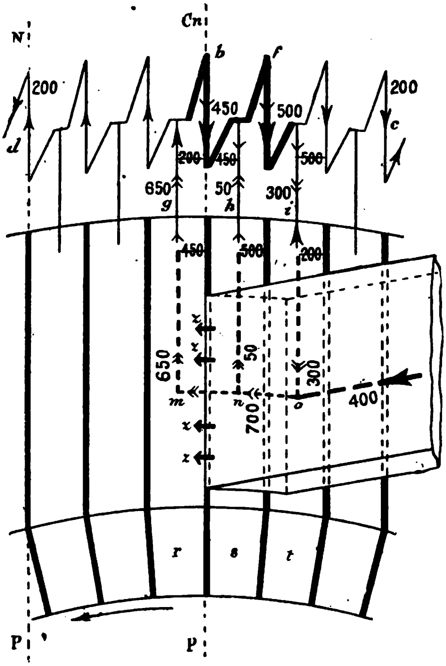

FIG. 120.—Negative Brush too far back. Heavy Forward Sparking. (Position B in Fig. 117.)

200 amperes to the *c* coils, and 200 to the *d* coils, the first-named 200 endeavour to flow out by the lug *i*. Here, however, this amount is baulked by the normal 500 *f* s.-c. current. The latter hence becomes reduced to a resultant 300 in *i o*, as indicated. Consequently, the first 200 become assimilated with the 500 *f* amperes in *o n*; and being joined by the other 200 entering by the brush, a total of 700 proceeds to *n*. Here the 50 pass up *n h*. The remaining 650 run on to *g*, at the outer end of which 200 diverge into the *d* series of coils, while the 450 run through *b*. This latter current, joined by the resultant 50 up *h*, makes 500 amperes in the coil *f*. At the outer end of *i*, 200 separate into coils *c*, leaving the 300 to continue down lug *i*, as we found at the commencement.

What we may here note is that the current broken at the recession is the *whole outer main current*, plus 250 amperes of the short circuit current. There is the whole self-induction of the outer circuit, together with the added effects of the short circuits, thus brought into play. As the outer circuit may include the field magnet coils, the sparking may here be very heavy; and with the large current, considerable burning will take place, principally, as it will be seen, at the expense of the brush.

Fig. 121 indicates the last of these four positions. The coil *b* here carries the 500 s.-c. current, and a resultant s.-c. 50 flows out through the lug *h*, as in the previous case. A normal 500 s.-c. current inflows through *g*, and a normal s.-c. 450 outflows through lug *i*. The 400 amperes now arrive at *o* by the brush. Of these, 200 would pass to the *d* series by lug *g*, but are met by the inflowing 500 *b* s.-c. current, and reduce that to 300 instead. They become assimilated with the s.-c. current, and so form part of the 450 s.-c. current outflowing through lug *i*. The remaining 200 of the outer current augment this 450, thus making a total of 650 finding exit by lug *i*. At the outer end of this lug, 200 split off to enter the *c* series of coils, while the 450 continue through *f*. This latter amount is joined by the 50 s.-c. current from *h*, making 500 amperes in coil *b*. Of these, 200 diverge into the *d* series, leaving the 300 to continue down lug *g*. Arriving at *n*, the 50 pass up *n h*, leaving only 250 to proceed to *o*. So the cycle of operations is once more completed.

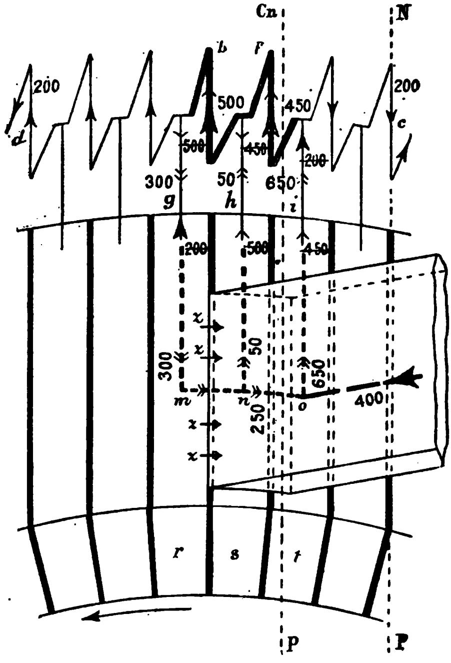

Fig. 121.—Negative Brush too far forward. Light Back Sparking. (Position D in Fig. 117.)

It will be remarked that we have back-sparking here, as in the case of the brush in position C; for it passes in the contrary direction to the main current. Moreover, as in the latter case, there are only 300 amperes broken, and these of short-circuit current. The sparking therefore will be merely that due to the self-induction of the short-circuited coils *b* and *f*. It will hence be slight; and with the small current the arcing will not be great, though the segment will suffer the most. As with the brush C, the main current passes through the heel of the brush, and not the point, and so escapes being broken.

We may now notice some general results and conclusions. Thus we observe that, as shown in connection with the diagram, Fig. 114, all these effects are produced by the assimilation of main current with the short-circuit current. Yet it is only *one-half* of the main current that is so assimilated, and hence diverted; and, inasmuch as by Ohm's law one half of the main current would flow through the point of the brush and the other half through the heel, it is simply a question finally as to which half of the main current shall be thus caused to diverge At the non-sparking point this divergence by assimilation is just precisely achieved, and all flow of current in either direction withdrawn from the brush point. But there is too much of the diverting s.-c. current when the brushes are too far forward, so that its surplus is broken and causes sparks. Whereas, when the brushes are too far back, not only is the divergence of main current in the wrong direction—that is, from heel to point—but there may be (and is, in the cases we have assumed) a surplus of the diverting s.-c. current also: hence, the grand total, composed of the *whole* of the main current and the surplus of s.-c. current, is broken, with violent sparking due to the self-induction of the main circuit as a result.

Another point that may engage our attention, concerns the position of the plane of commutation in relation to the variously misplaced brushes. On an earlier page we stated that this followed the brushes, *but with some degree of elasticity.* It will be observed that this plane, lettered Cn P in the diagrams, is shown in Fig. 117 (lettered Cn only) with each pair of brushes. At brushes A and B it runs through the points, while at C and D it passes through just within the heels of the brushes.

If we thus examine Figs. 118 and 120, showing brushes A and B, we shall observe that on the recession of segment *r*, and the breaking of the assumed current of 650 amperes, a *sudden* reversal is *forced* to take place in the coil *b*, by its being thrown completely among the series *c* in the former, and *d* in the latter. The coils *b*, in fact, in both these cases are thus suddenly commutated at that exact instant; and the current in them, subsequently, will run counter to their E.M.F., until the C F plane is reached, as explained in Chap. XVI. (p. 160). Hence the plane they are then in is the plane of commutation for those positions of the brushes; and if the plane of the coil runs through the points of the brushes, as shown in the diagrams, so also will the plane of commutation.

To turn now, however, to Figs. 119 and 121, showing brushes C and D, we find here that it is not the forward coils *b* that are first reversed, but the hindmost coils, *f*; and in the diagrams this reversal is assumed to have taken place, and *b* and *f* are both prepared to be thrown among the other series of coils they are approaching, excepting in so far as they are carrying a current which is too great. It will be noted that directly on the two segments *t* making contact with the heels of the brushes, the coils *f* will have become short-circuited. But up to that instant they have had within them the current direction and polarity of the coils *behind* the brushes. This has now to be reversed. But it has to be further remarked, that the E.M.F. in the coils between *f* and the N P plane, has already been reversed by the fact that, with brush C, they are on the *c* side of the C F plane, and with brush D are on the *d* side of C F. The reversal of the current is thus so far prepared for; and it is merely a case of overcoming the self-induction of coil *f*, which is now accomplished by the proper E.M.F., already acquired. As we have already pointed out, this reversal is not here necessarily sudden, for it takes place after a *making* of contact between the brush heels and segments *t*, and not at a break. Hence the exact position of the plane of commutation will be that plane occupied by the coils *f* when they have an infinitesimally small amount of the reverse current from *b* commencing to run in them—with which, it will be borne in mind, the current in the series of coils forward of the brushes, is assimilated. And this position, with the plane of the leading short-circuited coil cutting through the points of the brushes, we have assumed to be just forward of the heels, as indicated by the lines Cn P in the diagrams of the brushes C and D under discussion, and lines Cn in Fig. 117.

We have alluded to the fact that in the cases of the brushes at C and D, the currents broken at the recession of the segments *r* are merely short-circuit currents. A question might arise as to exactly in what manner the self-induction of these short-circuits takes effect, so as to produce sparking. Inspection, however, will show that this is due to the sudden reduction at the moment of recesion, of the 500 amperes in the coils *b*, to the normal 200 of the series of coils among which they are being thrown. For by the operation of Lenz's law, already dwelt on, so sudden a reduction will be resisted, in like manner, though not to the same degree, as a sudden reversal. Hence at the recession of *r*, a momentary very high E.M.F. will accumulate at the point of the brush, causing a discharge of disruptive sparks into *r*, followed by arcs, in the case of brush C; while the discharge will be from the segment *r* to the brush, in the position D. Both being contrary in direction to the main current, there is thus formed what has been termed back-sparking.

CHAPTER XXI.

SPARKING AT COMMUTATORS.—NON-SPARKING WITH CARBON BRUSHES.

It will not be inappropriate if we here devote a chapter to the subject of the comparative absence of sparking that attends the use of carbon brushes, to which reference was made on an earlier page,

It may thus be assumed that with carbon brushes there are two causes in particular that tend to prevent sparking. Of these, the first is the higher resistance of the substance as compared with metal: while the second is the resistance of the *contact* between the brush and the segments of the commutator. It is the latter which we shall endeavour to show is by far the more important in accounting for the absence of sparking; though the former may also have its effects.

Now, when carbon is used in any shape to form part of an electrical circuit, it is an understood thing that great care is always necessary in securing a good contact between it and any metal connection. Thus, in the case of carbons for a cell, we find the upper ends carefully encased in lead, and so a large surface of the actual carbon put in contact with that metal, to which latter terminals may be attached. Or again, as with the brushes now under discussion, it is considered distinctly advisable to thoroughly copper-plate the outer ends that go into the brush holders; and not merely the ends, but a great part of the whole brush. The conclusion is thus negatively deducible, and indeed generally recognised, that the contact between carbon and metal, even when the contact surfaces are as bright and smooth as they can become, is yet not so efficient for the passage of current, as the contact between two bright metal surfaces.

An immediate effect to be apprehended as a result of the combined non-inductive resistances of the contact between the carbon brush and the segments of the commutator, and of the carbon itself, will be the almost complete cessation of the short-circuit currents. For, as pointed out, these being impelled by but small electromotive forces, a small resistance only may reduce them to nearly or quite negligible amounts. We thus find that the theory of non-sparking dependent on short-circuit currents will not apply in the case of carbon brushes.

Now we have mentioned that, apart from the interposed effects of the short-circuit currents, the main current will simply follow Ohm's law in its flow to and from the brushes. We also called attention to the fact (page 171) that as an outcome of this law, the current, having two or more paths in which to flow, would divide itself among these in inverse proportion to their several resistances. But we then concluded that (with the metal brushes), as two of the paths traversed coils having resistance, most of the current would flow through the one path of practically no resistance; and the flow through the coils might be considered negligible. In the case under discussion, however, this conclusion requires to be modified.

Fig. 122, herewith, illustrates part of a commutator as in previous diagrams, rotating in direction indicated by the curved arrow. The hatched portion represents the contact surface of a carbon brush, extending equally over the segments *r* and *s*. One coil only, *b*, is thus short-circuited; and what short-circuit current may be generated is indicated by small arrowheads, as heretofore, the brush being assumed at position A in Fig. 117.

Now it is obvious that, taking the simple resistances alone into account, and with the *c* and *d* currents opposing each other equally in the coil *b*, the whole of the *c* current will pass through lug *g*, and the *d* current through lug *h*. But two circumstances will here require attention. First, whereas with the metal brush the disparity between the resistance of the one path through the lug *g*, and the resistance of the path or paths through the coils *b* and *f* was considerable; with the carbon brush, on the other hand, inasmuch as an additional resistance due to the contact is inserted in each path, this

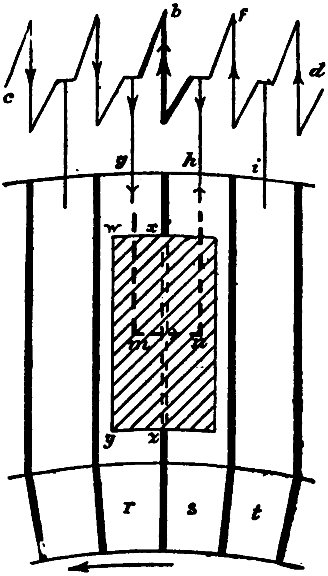

Fig. 122.—Carbon Brush. Short-Circuited Coil not reversed.

disparity between the resistances of the different paths is diminished; and, as further, these inserted resistances are of a varying nature owing to the advance of the segments, the disparity may at times even be reversed, so that the total resistance of a path through a coil, may be less than that through the lug *g*. Secondly, whereas in the case of the metal

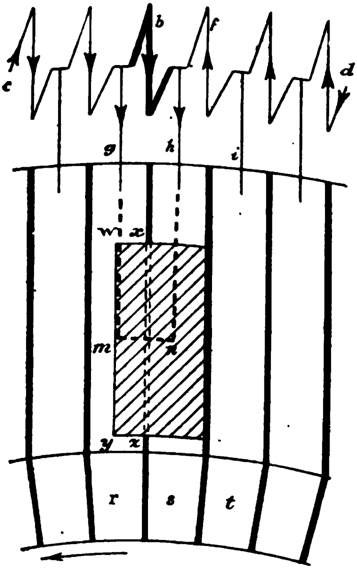

Fig. 123.—Carbon Brush. Short-circuited Coil commutated.

brush at A, a large short-circuit current would be generated in *b*; which by assimilation would divert the entire flow of the *d* current from *h* into *g*, and so both the *c* and the *d* currents would flow through *g*; with the carbon brush, owing to the *smallness* of the short-circuit current, the divergence of main current by that means would also be extremely small. We thus find that, whereas with the metal brushes the second count, that is, the question of short-circuit currents, was all important, with the carbon brush, on the other hand, it is the *first* count, touching on the varying resistances of the contacts between the carbon and the segments, that is of the greater consequence.

Turning now to Fig. 123, wherein a slight rotation of the commutator beyond the position shown in the last diagram is assumed, we find that the brush contact on segment *r* is but little more than half that on segment *s*. Hence the resistance of the contact area *w x y z* will be nearly double that of the contact on *s*; and the sum total of resistance by *g r* into the brush, will be much greater as compared with that by *b h s*, than it was in the last diagram. Consequently, a much more considerable proportion of the *c* current will tend to flow by way of *b h s*. But the *d* current obeys the same laws as the *c* current: it has one path of minimum resistance by *h* and the contact on *s*, and another path of greater resistance by *b g r*. Taking *c* and *d*, however, jointly, and ignoring for the moment the resistance of *b*, we find that of the total flow, about two-thirds will pass by *h s* and one third by *g r*, in proportion to the contact areas respectively on the two segments. Hence a flow of main, that is of *c*, current, will pass through *b*; and unless the short-circuit E.M.F. generated singly by the coil or section of winding *b*, operating against the resistance of both the contacts on *r* and *s* and the resistance of the carbon, is able to impel a s.-c. current of greater strength than—which would also be in the opposite direction to—the main *c* current in *b*, then the s.-c. current in *b* will be eliminated; and in fact the coil *b* will be commutated. It has to be noted, however, that the resistance of *b* will have a damping effect on the passage of current through it, whichever the direction of the flow. If the resistance should be very great in comparison with that of the contacts on *r* and *s*, the flow of *d* current would obviously be confined almost entirely to the lug *h*, and the *c* current to the lug *g*, up to the moment of recession. But further, the self-induction of *b* will offer opposition to a rapid commutation of its original *d* current direction and polarity to those of the *c* current. It will, however, thus be perceived that if both the resistance and the self-induction of the short-circuited coil or section of winding *b*, are *small* as compared with the resistance of the contacts of the carbon brush on the segments *r* and *s*, an early commutation of *b* may take place, soon, in fact, after the area on *s* has become greater than that on *r*, as represented in the diagram.

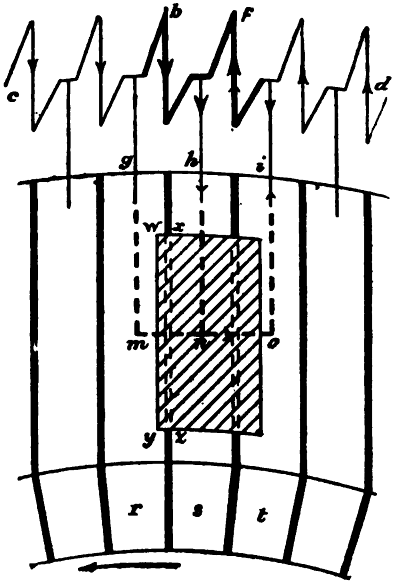

FIG. 124.—Carbon Brush. Diversion of Current from Forward Edge of Brush prior to recession, owing to Resistance of Contracted Contact on Receding Segment.

The effect of the alteration to the conditions depicted in Fig. 124 may now be considered. We observe that, owing to the contraction of the area *w x y z* with the rotation of the commutator, the resistance of the path by lug *g* and segment *r* into the brush is greatly increased; while, on the other hand, another entry into the brush has opened up by the lug *i* and segment *t*. The coil *f* is short-circuited as well as *b*, though not as yet commutated; and the *d* current may enter the brush by the paths *i t* or *f h s*. But *b* being commutated, and the resistance by *g r* becoming considerable, the *c* current will continue to flow more by *b h s* and less by *g r*, up to the moment of recession. Hence at the recession finally of segment *r* from the brush, there will be little or no current flowing between them, and so little or no sparking.

It has now to be remarked that the above line of argument will apply to all positions of the brush, as at A, B, C, and D, Fig. 117, or any position between. For a positive or negative lead given the brushes simply affects the direction of the short-circuit currents; and these we have shown to be of but little importance with carbon brushes.

The forward edge of the brush, *w y*, is found liable in practice it would appear, to get very hot. This is thus to be accounted for by the fact that, owing to the resistance offered by the self-induction of the coil or section of winding, *b*, to the *continued increase* of the *c* main current through it, the current density through the area *w x y z* is abnormally high, as compared with that through the rest of the contact. But further, inasmuch as the ratio of the area *w y x z* to the remainder of the brush contact area, diminishes, not at a constant rate, but at an *increasing rate*: so also the rise of *c* current through *b* is not uniform, but takes place at an *increasing rate*, especially increasing at the last instant up to the actual recession. Thus the self-induction of *b*, tending to retard the increase of *c* current through itself, acts more powerfully as the moment of recession approaches, or in other words, as the area, *w x y z*, becomes infinitesimal. Hence, as this area narrows to a mere line, the current density through it increases up to a maximum at the moment of recession. The edge *w y* gets heated; while, nevertheless, the actual total amount of current passing is too small to produce sensible sparking.

It would appear that carbon brushes have been used with a current-density approaching 200 amperes per square inch. But 40 or 50 amperes per square inch of contact surface is given as a practical maximum, and 30 amperes as a safe working density, as the result of experience. Discussion and correspondence on this subject may, however, be found in *The Electrician*, Vol. XXIX., pp. 192, 233, 265, 270, 287, 288, 437.

CHAPTER XXII.

◆

SPARKING AT COMMUTATORS.—CAUSES EXTERIOR TO MACHINE.

We are now about to enter on another distinct branch of our subject. Hitherto we have dwelt principally on the direct causation of sparking at the commutator. But there are other points which, though seemingly direct causes of sparking, are nevertheless more correctly perhaps, to be regarded as indirect causes. To these we have already made some slight allusion; and we refer to those faults or accidents in a machine or the circuit, which lead to the oscillation or deflection of the normally fixed planes. For, as we have pointed out, the oscillation, or partial rotation backwards and forwards round the axis of the shaft, of these planes, amounts virtually to a shifting to and fro of the brushes in relation thereto. In the case of such oscillation, therefore, it is the disagreement between the positions occupied respectively by the brushes, and the normally fixed planes, that is the ultimate direct cause of the sparking that would ensue.

The stability of all the normally fixed planes, such as the planes of maximum and minimum potential, of requisite reversal, and of non-sparking (*see* Chapter XVI.) is dependent on the fixity of the centre line or plane of distortion lettered

$y\,y$ in the diagrams, and consequently on the invariability of the angle θ between $y\,y$ and $x\,x$ in the same diagrams. An exception that may be taken in respect of the plane of requisite reversal, is that inasmuch as this forms an angle with the C F plane through the armature, which latter plane is invariably perpendicular to $y\,y$, the angle θ may open to the same extent that the angle between R R and C F may close; and *vice versâ*. Hence in this latter case, the plane of requisite reversal, and consequently the non-sparking plane through the commutator, will not oscillate, although the angle θ may slightly vary. But apart from this contingency, the position of $y\,y$ affects that of all the normally fixed planes; and the slope of $y\,y$, or in other words, the extent to which the angle θ may be open, depends on the ratio of the strength of the field to the strength of the self-polarisation of the armature. It is thus this ratio with which we have ultimately to deal.

This question may obviously be affected by any of the following causes. The strengthening of the self-polarisation of the armature, and the weakening of the field, one or both, will open the angle θ; while conversely, the weakening of the armature self-polarisation, and strengthening of the field, either or both, will close the angle. A tendency for the normally fixed planes to become bent or deflected at the axis of rotation, is also such as may be subsequently considered.

These causes may now be internal and inherent to the machine; or they may be altogether external. As the former are those that will require the most consideration, we may dispose of the latter first, which will hence form the subject of this present chapter.

External causes of sparks and flashes at the commutator (due directly to the oscillation of the normally fixed planes) may be a "short-circuit" between the positive and negative leads or terminals, "earths," or changes of "load." The effects, however, apart from such other consequences as the burning of insulation or of the armature winding, throwing off of the belt, or pulling up of the engine, may vary according to the manner in which the machine is wound, and as to whether the cause is gradual or sudden.

Figs. 125 to 128 illustrate variously, separately excited, shunt, series, and compound wound dynamos. The outer circuit in each is represented by the dotted lines *a b* and *c d*; while the line *a c* will represent a "short-circuit" between the positive and negative leads, whereby the whole outer circuit is cut out. At E and E′ are indicated leakages to earth. The effect of leakages into the ground will depend on circumstances. Ordinarily the earth is a bad conductor for large currents; and it does not answer to use it as a return lead. Damp or wet earth, and especially the near presence of any iron piping or other metal conductor running from one leakage to the other, would then, of course, render the effect approximate, more or less, to that of a short-circuit. The short-circuit, as shown at *a c*, may be of more or less gradual growth, such as might arise from the perishing of some insulation, taking some little time to happen: or it may be quite sudden, owing to some accident, such as a metal bar falling across, and so electrically connecting, a positive and negative terminal on a switchboard.

To consider the gradually growing short-circuit first—which may, however, be only a matter of a minute or so, or but a few minutes—we find that as the fault increases, the current will flow more and more through it, instead of through, and against the resistance of, the outer circuit *c d b a*; for as the term "short-circuit" implies an absence of resistance, so the path *a c* will offer ultimately practically no resistance. Now as we explained in Chapter XIX., when a machine has an outer circuit between the brushes offering little or no resistance, the outer voltage, or potential difference between the positive and negative brushes, will correspondingly vanish. The whole

E.M.F. of the machine is used *internally*, and is employed in impelling current through, and against the resistance of, the armature winding *only*. This is precisely the effect produced by the short-circuit; and hence an enormous current will flow. Apart from other consequences, this will at once cause an immense increase in the strength of the self-polarisation of the armature.

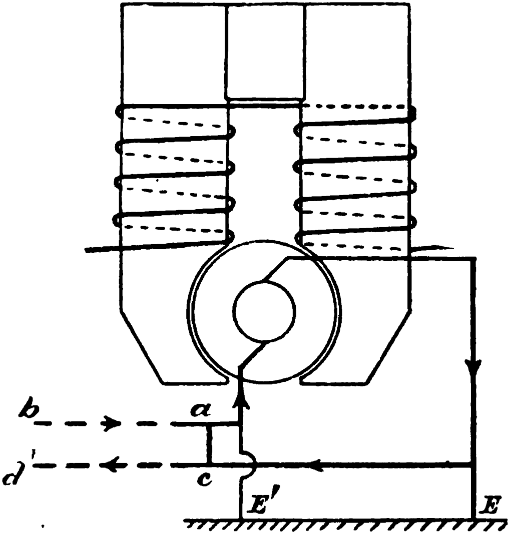

FIG. 125.—Separately-excited Machine, with Short-Circuit and Earths.

Now, in Fig. 125, where the magnet coils are on an independent circuit, it will be observed that the field is not directly affected by the increased current. Therefore, the armature polarisation being increased, while the strength of the field is unaltered, the angle θ will be widely opened, and all the normally fixed planes will oscillate forward to suit. This, it will be noted, is the same as though the brushes were shifted too far backwards. There will hence be "forward sparking" of violence concomitant with the backward position, as explained in Chapter XX.; and the flash will be very great owing to the immense flow of current. For the arc of the flash will be large, and the heat great, and the brilliancy will be due to the burning metal of the brushes and commutator segments, the presence of any zinc in the metals imparting a green tinge to the flame. If, further, the brushes

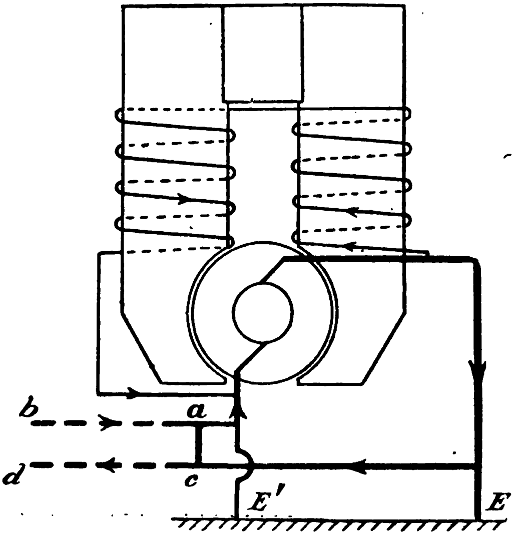

FIG. 126.—Shunt-wound Machine, with Short-Circuit and Earths.

should have had lead, permitting back-induction, this latter effect would be intensified by the rush of current through the armature. Hence, the field would now also be weakened, and thus cause the angle θ to become still further opened.

In Fig. 126 the field is directly affected by the gradual short-circuit. For, owing to the disappearance of the exterior voltage, there is now no potential difference between the two ends of the shunt, and so no current will flow through it. Consequently, owing to its dependence on the shunt, the field will be reduced in strength to zero, or nearly so. The total E.M.F. will fall. But what little remains will send current through the armature, causing the strength of its self-polarisation to become abnormally high in proportion to the (remaining) strength of the field. Hence θ will open, with forward sparking as a result.

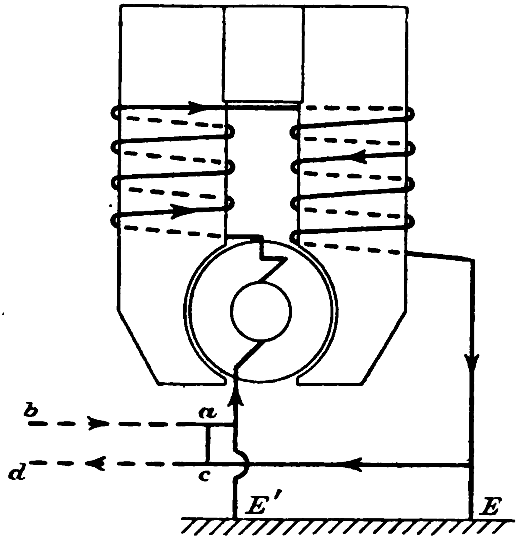

Fig. 127.—Series-wound Machine, with Short-Circuit and Earths.

The above cases, however, assume a gradually formed short-circuit. If this were instead to occur suddenly, the effects, especially in the case of the shunt wound machine, would be different. For, owing to the fact that the inductance, or self-induction, of the shunt coils would be considerably greater than that of the armature winding, and also on account of the hysteresis of the magnets, the field would not become reduced so quickly as the current in the armature would increase. If anything, indeed, by the laws of self-induction (as explained in Chapter XV.), at the first instant the field would be strengthened by the extra current through the shunt that would immediately precede the ultimate reduction of its main current. The total E.M.F. would, therefore, not immediately fall, and would possibly rather rise for an instant. In any case, however, the whole E.M.F.

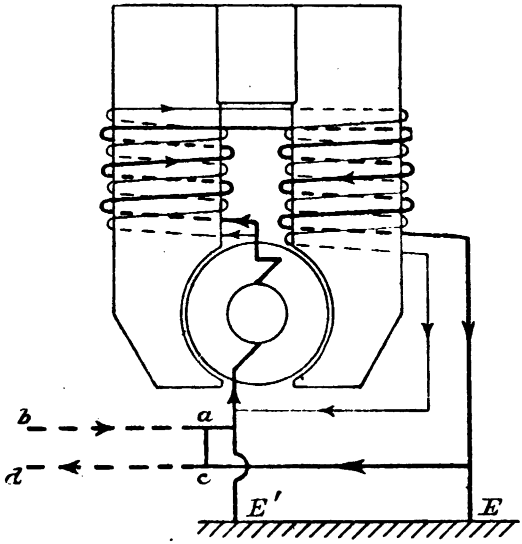

Fig. 128.—Compound-wound Machine, with Short-Circuit and Earths.

being used for overcoming the armature resistance only, much the same effects must follow, as described above in connection with the separately excited machine, Fig. 125, and θ will open.

To take the case of a series-wound dynamo, as illustrated in Fig. 127, we observe that a short-circuit in the outer circuit would result in a large current flowing not merely in the armature, but also through the field windings, assuming these not to be cut out. The field will strengthen almost proportionately with the strength of the armature self-polarisation: that is, if the rush of current is not too sudden. Hence, the angle θ may not sensibly vary; and there will be little or no sparking. It is to be noted that, owing to the resistance of the field magnet windings, some E.M.F. will be maintained outside the armature between the brushes, and the great increase in strength to the field due to the increased current in the magnet winding will cause the *total* E.M.F. to rise. Most of this will be used in overcoming the resistance of the magnet coils, which will be greater than that of the armature. But as the major part of the outer circuit is short-circuited, a larger proportion of the total E.M.F. will be used up in the armature than would otherwise be the case. A fact bearing on this point, however, in the case of series machines, is that if the short-circuit is only partial, or at least not absolute, so that some resistance in the exterior circuit between the brushes still remains, then, up to a certain limit of decrease of exterior resistance, the exterior voltage, or potential difference between the brushes, will *rise*. This is owing to the increasing current through the field coils. But with a decrease of outer resistance beyond this limit, the want of exterior resistance commences to have a direct effect in reducing the outer voltage, in the manner already explained, as with a shunt machine.*

With the same reasoning as before, it will be observed that a suddenly occurring short-circuit, with a series winding also, will not develop its full effects at once. For owing to the self-induction of the armature winding being considerably less than that of the field magnet coils, and also on account of the hysteresis of the magnets, the armature polarity will be affected much sooner than the field. Hence, at the first instant, the angle θ will open, causing a flash of forward sparking at the brushes. It will be remarked further that, in all cases, a merely momentary short-circuit would be unable, from want of time, to develop all the results that would be permitted by a longer endurance.

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* Reference, for further explanation on this point, may here be made to Prof. S. P. Thompson's "Dynamo-Electric Machinery," page 264 (fourth edition)—more especially to a diagram there numbered Fig. 164.

It may now be noted that, in the above instances, a gradual or sudden *change of load* will but have the same effects, though perhaps less in degree, to the gradual or sudden short-circuit. If it be attempted, for instance, to use these machines for incandescent lamps in parallel, a number of lamps switched on would be tantamount, more or less, to introducing a short-circuit. More current would flow; in the separately excited and shunt machines the angle θ would open, with consequent forward sparking: while a similar effect on the angle θ would follow in the case of a series dynamo, should the introduction of the lamps be sudden. The brushes may be advanced to their new non-sparking positions. Suppose, now, the same lamps were switched off again. This would be equivalent to introducing a *resistance* into the outer circuit, instead of a short-circuit; and opposite effects would arise. The angle θ would close, with back sparking as a result: and whereas the exterior voltage would have fallen when the lamps were switched on with the separately excited and shunt machines, and would have risen with the series machine, the contrary effects in this latter respect also, would arise on the lamps being switched off again.

It is thus that in order to achieve the successful running of incandescent lamps in parallel, wherewith a steady and unvarying exterior voltage between the brushes is necessary, howsoever the current may vary, the method of compounding the above systems of winding has been adopted. Thus, shunt and series machines being affected in opposite ways as regards the outside voltage, by the same changes of load, a machine may be "compound wound" on both these systems; it may be shunt wound, and also have some series coils taking the main current round the magnets. This is illustrated in Fig. 128, where both windings are shown, the main by a thick line, and the shunt by a fine line. Hence, on a number of lamps in parallel being switched on (or a small short-circuit occurring), the extra flow of current will also go round the magnets in the few series coils. By strengthening the field, this will cause an increase to the total E.M.F. We have already observed that an increased current will require a higher E.M.F. to force it through the armature, and further, that with a *given total* E.M.F., and a *decrease* of resistance outside, a larger proportion of this total E.M.F. will be used *within* the machine as a fact, to drive the larger current through the armature, *at the expense of* the outer E.M.F. Thus, the compound winding may be so arranged that, when the current increases, the *total* E.M.F. will also rise, so that the extra voltage will always be sufficient to drive the increase of current through, and against the resistance of, the armature, and the series coils on the magnets. In other words, the additional E.M.F. is entirely used *within* the machine; consequently, the *external* voltage remains unaltered, as required. It will thus be observed further, that the shunt current being led off from the brushes, and the potential difference between these now being constant, a constant and unvarying current will flow through the shunt. Thus the latter will steadily maintain its share of the total electromotive force of the machine, and will maintain the exterior constant voltage required for the variable current for the lamps, according to the number that may be in circuit; while the series winding will overcome the internal resistance of the machine.

But these conditions, moreover, will subserve to the reduction of the oscillation of the normally fixed planes, especially the plane of requisite reversal (*see* Chapter XVI.). For, referring back to Fig. 111, when the *c* and *d* armature currents are increased, and it becomes necessary that the *b* short-circuited coil shall have had its current made equal to the *c* current, on its arrival into the same position, at the same angle with the vertical, as before, we find that the strengthened field may enable this to be accomplished. That is, the plane of requisite reversal will oscillate but little, or not at all; and the neutral plane, or plane of non-sparking through the commutator, being either coincident, or at a mechanically-fixed angle, with the R R plane, the non-sparking points will remain equally stable. Consequently, it is to be observed that in the ideal compound dynamo, under any change of load within wide limits, while the exterior voltage may be maintained at a constant value, the sparking will be practically eliminated.

The reader desirous of entering more deeply into the subject of compound winding may be referred again to Prof. Silvanus P. Thompson's "Dynamo-Electric Machinery," pp. 263 to 265, and 289 to 300 (fourth edition).

CHAPTER XXIII.

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SPARKING AT COMMUTATORS.—ARMATURE REACTIONS: FIELD WEAK.

CASES may now be considered in which the oscillation, or the permanent deflection, of the normally fixed planes may result from causes internal and inherent to the machine, and thus lead to more or less incurable sparking. These causes may be various in character. Oscillation of the planes may be brought about by a want of symmetry, or by a defective joint, in the armature winding. A permanent deflection through the axis of rotation may be caused by a want of symmetry, or *asymmetry*, in the field; or, again, the normally fixed planes may have an undue inclination toward the centre plane of the field, owing to the strength of the self-polarisation of the armature being too powerful in proportion to that of the field. It is this last cause which we propose to discuss in this present chapter.

In Fig. 129 herewith are represented diagrammatically some of the effects that may arise from undue weakness of the field. The armature winding, which may be considered as of either the drum or the Gramme type, is indicated by the radial lines *a a* and *b b*. For the sake of simplicity the commutator is omitted; and the brushes are shown resting directly on the armature.

Now in Chapter VIII., in connection with Figs. 50 and 51, we descanted on "back-induction," and "cross-induction," produced respectively by the coils approximately normal to, and parallel to, the lines of force of the field. The same remarks

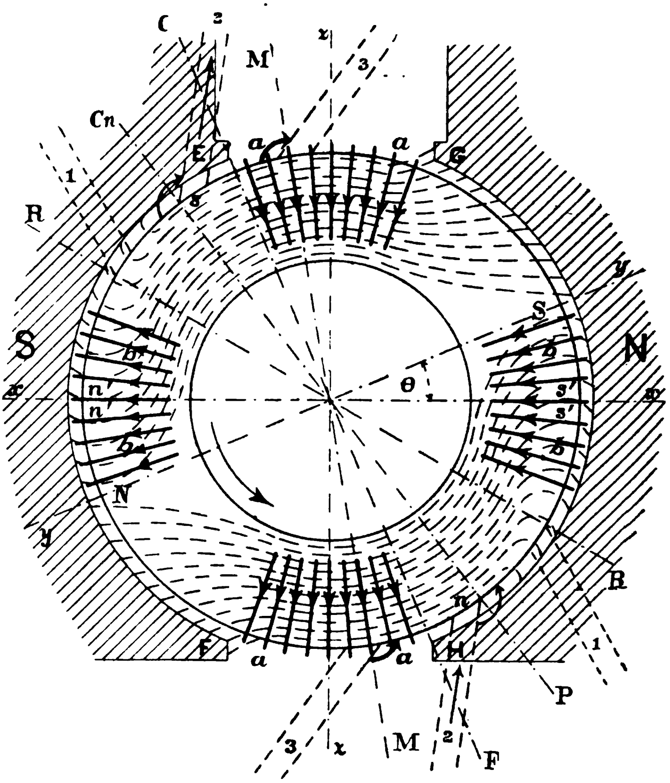

Fig. 192.—Diagram illustrating Armature Reactions (with Brushes at 2, 2) and Sparking due to a Weak Field.

will apply in the case before us, where we find, consequently, that the coils *a a a a* are exercising back-induction, and the coils *b b b b* exercising cross-induction, or cross-magnetisation, as it may otherwise be termed. These effects are what are known as "armature reactions"; and, in proportion as the armature self-magnetisation is strong, and the field weak, so will their influence preponderate. As we are assuming a weak field, it is these armature reactions thus that we now find are of special relative importance.

It has to be observed, however, that these two inductions, normal to each other, are in reality only the *components of the armature self-polarity*, which latter may consequently be regarded as their *resultant*. This may be rendered more clear by Figs. 130, 131, and 132. These show an armature revolving in a field, with brushes; but with the latter in three different positions. The self-polarity, which we have already shown (Chap. XVI., pp. 158, 159) must follow the brushes, is represented by the thick line *s n*, which letters may also signify south and north respectively. Thus, in Fig. 130, where the brushes have a forward lead, the lines *s c* and *a n* will indicate the back-induction, and the lines *c n* and *s a* the cross-induction. Hence, lines, one of each of these inductions, for instance, *a n* and *c n*, may be regarded as *components* of *s n*. In Fig. 132, the brushes are shown with a negative lead; and it will be observed that, while *c n* and *s a* still act vertically in the same direction as in Fig. 130, though they have exchanged positions, *s c* and *a n* are *reversed*: and although *c n* and *a n* still continue components of *s n*, yet the induction *s c* and *a n* represent is now in the same direction with that of the field, which of course runs from N to S. Hence the latter has been termed *forward*-induction, inasmuch as it *assists* the field, in contradistinction to the *back*-induction, which *opposes* the field. In Fig. 131, *n s* being vertical, the cross-induction alone remains: that is, the whole self-polarity of the armature is exerted in this direction; and there is no resolution of *s n* into components, as in the other two cases.

Thus, in investigating the armature reactions in a field, it may be convenient sometimes to regard the resultant *s n* alone,

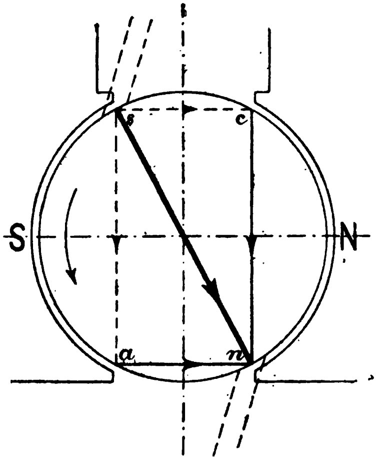

FIG. 130.—Cross-induction and Back-induction.

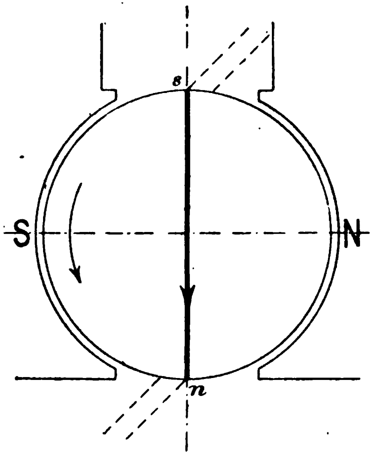

FIG. 131.—Cross-induction only.

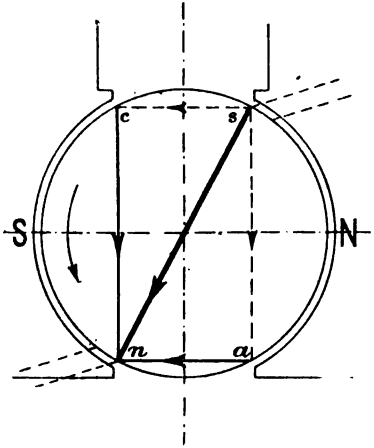

FIG. 132.—Cross-induction and Forward-induction.

Diagrams showing Resolution of Armature Self-Polarity into Two Component Inductions respectively parallel to, and at right angles with, the Field.

and at other times to consider its components instead. For our immediate purpose, it will be better if we view these reactions in the light of their resultant only—the armature self-polarity.

To examine more closely, therefore, the conditions of the armature itself, we know that its actual, or ultimate, polarity, is a compromise between two influences. The first of these is the armature self-excitation, tending to produce the self-polarity *s n* just enlarged on: while the second is the field induction, tending to induce a different polarity, as indicated by *s′ n′*. These two influences being thus at variance with each other, the *ultimate* polarity, indicated by S and N, is a compromise between them. But it is the former of these, the self-polarity, *s* and *n*, movable with the brushes, which may none the less continue chiefly to engage our attention.

With a lead given the brushes as shown, it will be observed that these two poles of the armature come exactly under the horns E and H; *s* opposed to an **S** horn, and *n* opposed to an **N** horn. Consequently, we find the full strength of the self-magnetisation of the armature directed to the reduction of the normal polarity of these horns. According to the mutual strengths of the opposed poles, the effects will be as follows: either the horns E and H will have their normal magnetism weakened; or they may be entirely demagnetised; or if the *s* and *n* poles are very strong, the horns may even have their polarity reversed, and the horn E will become north, and H south.

This latter eventuality, however, is more liable to occur with a Gramme winding than a drum. For, as pointed out in Chapter I., p. 12, and illustrated in Fig. 133, the self-excited poles (*s* and *n*, Fig. 129) of the drum armature are broadened and spread so as to occupy generally two opposite sides of the core: whereas with the Gramme winding, wherein each half of the armature tends to have its self-excited North pole exactly at *n*, and its South pole exactly at *s*, the two self-excited poles of the armature as a whole become much more acutely localised or confined to two mere lines, or narrow strips of surface, on opposite sides of the core parallel with the axis, as indicated in Fig. 134. Hence, with the latter, the full strength of its self-magnetisation is brought to bear with much greater effect on the horns it may oppose, than would be the case with drum-winding. This is, hence, another respect in which the drum armature has a distinct advantage; and inasmuch as a large armature will have more powerful self-excited poles than a small armature, a larger size of drum armature may be safely used without risk of reversing the horns, than would be the case with a Gramme.

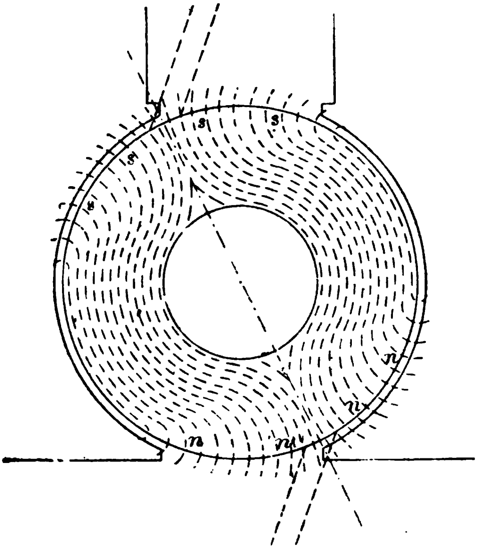

FIG. 133.—Diagram representing Self-excited Polarity of Drum Armature.

In the diagram, Fig. 129, it is assumed that the horns E and H are simply demagnetised. In consequence of the shifting forward of the self-excited poles *s* and *n* with the brushes, the angle θ will open; and inasmuch as the poles *s* and *n* are abnormally strong, this angle will open wider than would otherwise be the case; and thus the field is greatly distorted. The C F plane, invariably perpendicular to *y y* (*see* Chapter XVI.), is also tilted as shown; and an effect to be noted is that the induction lines flowing in and out from the pole-pieces, as shown dotted,* become very cramped or dense towards

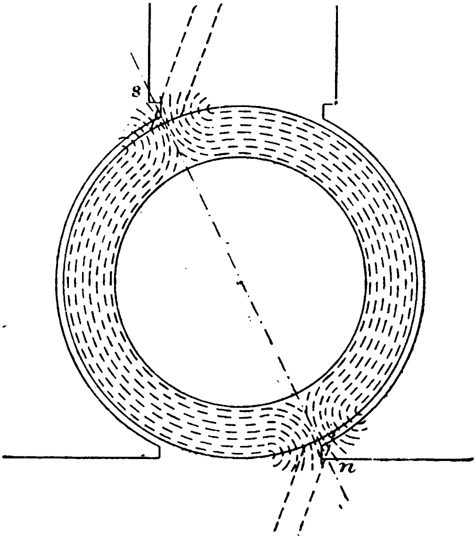

FIG. 134.—Diagram representing Self-excited Polarity of Gramme Armature.

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* It should be stated that the curvature given to the ends of these dotted lines is only suggested, inasmuch as it is a departure from the more usual method of showing them arranged symmetrically either side of an imaginary straight centre line through the axis, as *y y*. The assumption is

and at the horns G and F, which hence, contrary to the case with the other horns, become strongly magnetised.

We may now notice some further effects that will arise with a weak field. Referring hence again to the diagram, Fig. 129, the plane of maximum E.M.F. will be observed, represented by the line M M. If the brush points thus are placed exactly in M M, there will be the maximum potential difference between them. It is to be observed, however, that the *s* and *n* poles being then brought, together with the brushes, nearer to *z z*, they will not so directly oppose the horns E and H; and these will consequently not be so much weakened. The horns G and F, on the other hand, will be strengthened, by the nearer opposition of the unlike poles, *s* and *n* respectively. But bearing in mind, that, to secure an absence of sparking, it is necessary that the short-circuited coils, before receding from the brush points, should not merely have been commutated, but should also have their polarity and current made equal to those of the coils they are about to join, we find that as there are only a few lines of force passing between the armature core and the horns E and H, no sufficient reverse E.M.F. can be generated to reverse the current in the short-circuited coils when the brushes are anywhere near the top and bottom. It is only when they are moved far forward, as shown dotted, in

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that with a rapidly rotating armature, the tendency of the iron, due to hysteresis, not immediately to respond to the magnetising forces acting on it, though possibly overpowered in a strong field, may yet, perhaps, take effect in a weak field in some such manner as shown. The point may seem of little consequence; but its importance will depend on the extent to which, under any given circumstances, the effect may take place. This, however, trenches on a subject on which it is not practicable to enlarge within the scope of these present remarks. Readers desirous of studying hysteresis may be referred to Prof. J. A. Ewing's book "Magnetic Induction in Iron and other Metals," or to the same work in *The Electrician*, Vol. XXVII., more especially to pages 517, 518, 546, 547 and 602. But it should be understood that there is no intention to imply here that the latter writer is in any way directly responsible for the above suggestion.

positions 1, 1, so that the coils may be excluding not only a sufficient *number* of lines, but excluding them also at a *rate* sufficient to generate the necessary E.M.F. and current (*see* Chap. I., p. 8), that the sparking will cease. Thus the plane of requisite reversal, lettered R R, is very far forward. Consequently, when the brushes are in the M M plane, or anywhere near the top or bottom, as at positions 2, 2, or 3, 3, being behind the R R plane, violent forward sparking will occur, as at the brushes in positions A and B, Fig. 117, and indicated by the curved arrows.

To consider the armature reactions in the aspect of the components, that is, of the two inductions normal to each other, as illustrated in Figs. 130 and 132, we find that, whereas, when the brushes are forward in positions 2, 2, in Fig. 129, back-induction results ; if the brushes should be moved back toward the horns G and F, as at A and B in Fig. 117 just alluded to, *forward*-induction will ensue: for the coils occupying the positions *a a a a* would have current circulating in them in the reverse direction to that indicated in the diagram.

Now, as forward-induction strengthens the field, this might appear an advantage. A point, however, in this connection may be touched on, bearing reference to the diagram, Fig. 117, in Chapter XX., which was not then dealt with. It will be observed, that when the brushes are shifted back to positions A and B, and the *s* and *n* poles are respectively opposed to the horns G and F, *unlike* poles being then opposed, these horns are strengthened, and the lines of force will gather about them yet more densely than when they are not so directly opposed by the armature poles. Hence we perceive that when the brushes have a negative lead, the short-circuited coils are traversing a denser field than they would traverse when the brushes are forward, even in the case of a normally strong field ; and consequently they will generate a more powerful E.M.F., which will impel a larger s.-c. current, than when the brushes are forward. Thus, when the brushes have a negative lead, not only is the s.-c. current circulating in the wrong direction for sparklessness, and diverting all the current flow to the brush points, as shown in Figs. 118 and 120, but it is also stronger, and has more efficacy in accomplishing the evil results. Hence any apparent gain from forward-induction is entirely counterbalanced by the evil results that also attend that particular reaction. With a very strong field a difference of density of lines of force under the horns, according as to whether the brushes are back or forward, would, of course, not be so marked as with a weak field. It may be noted that it is for this reason that, in the diagrams Figs. 117 to 121, the brushes are shown with a greater *positive* lead (as at C and D) than a negative lead (as at A and B), so that the same strength of s.-c. current may be assumed in each position.

In the case of a motor, the conditions being assumed the same as in Fig. 129, as regards **N** and **S**, and the position of the brushes, the current direction would be reversed, and the self-excited poles *s* and *n* would consequently exchange places. The horns E and H would then be *strengthened* by being opposed by unlike poles. If the pole pieces were not normally magnetised, yet the magnetism induced within the horns E and H by the armature would pervade those regions of the pole-pieces, so that they would attract the poles of the armature, and thereby cause the latter to rotate. The inverse of this holds good also—that is, the case of the dynamo brushes shifted too far back. For, as pointed out, the horns G and F would be strengthened by the dynamo armature; and so, if not normally magnetised, magnetism would be induced in them by the armature poles. Hence, the armature would create its own field. But the forward sparking would still take place, involving loss of energy and destruction of material.

When the motor brushes are forward and the motor armature is creating its own field by induction, it has to be borne in mind that the short-circuited coils will behave like the coils of a *dynamo* armature, and will similarly be *generating* a short-circuit E.M.F. and current. Thus the s.-c. current will circulate in the same direction as in the coils *b* and *f* in Fig. 119. But with the motor the main current will be flowing in the opposite direction. Hence Fig. 120 will represent the motor brush at position C in Fig. 117; and it will be observed that heavy forward sparking will occur, as with the dynamo brush too far back.

Reverting, however, to the weak field of a dynamo, as represented in Fig. 129, it has to be noted that the plane of maximum electromotive force being represented by the line MM, the further the brushes are shifted from this plane the less will their potential difference, that is, the outside voltage of the machine, become. For as the positive brush descends on one side below the point of maximum potential, so the negative rises on the other side above the point of minimum potential. Hence on advancing the brushes in order to attain a non-sparking position, the efficiency of the machine is sacrificed. It is thus that a field, too weak in proportion to the self-magnetisation of the armature, presents one of those cases wherewith sparking is practically hopeless.

NOTE.—It is necessary to observe that the word *demagnetised*, as it appears on pages 219 and 221, should be understood to refer *only* to the stoppage of the *flow of induction lines* from the pole-pieces into the armature, or *vice versâ*. The word, as here used, is not intended to imply that there may be no "free" magnetism from the parts under consideration *outside the field*. In subsequent Chapters the word "counteracted" will be used where this particular meaning is alone intended.

CHAPTER XXIV.

SPARKING AT COMMUTATORS.—ARMATURE REACTIONS: MAGNETIC FLOW.

In our last chapter we touched on the fact, in connection with Figs. 130 to 132, that the self-excited polarity of the armature might be resolved into two component inductions, respectively parallel and normal to the field. We also remarked that the armature reactions might thus be studied either in the light of the self-polarity merely, or else by considering the separate components.

It so happens that this latter method affords special advantages for the elucidation of some of the reactions that take place in the field. We have already to a slight extent treated our subject in this manner. But it is our purpose now, however, in this present and succeeding chapters to adopt this method of investigation yet more thoroughly, and so to prepare the way to practical conclusions not otherwise, perhaps, so easily attainable. With this object in view, we shall thus find it necessary to consider somewhat more closely than heretofore, the precise nature of magnetism itself.

Now, it will be well understood that, *within properly proscribed limits*, lines of magnetism may be regarded as forming a *current*, similar to electricity. If an intact ring of iron is magnetised by a coil and electric current round a part of it,

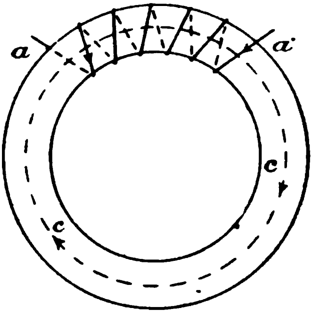

Fig. 135.

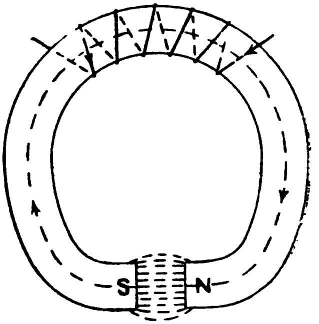

Fig. 136.

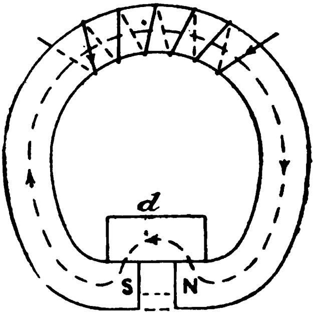

Fig. 138.

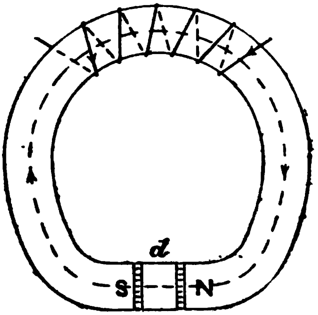

Fig. 139.

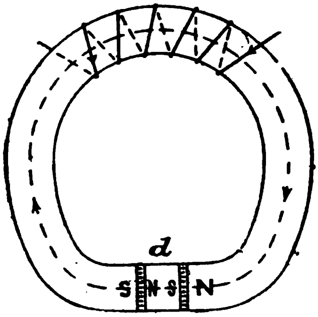

Fig. 140.

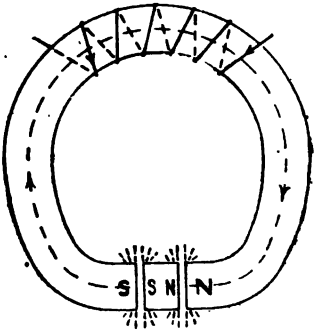

Fig. 141.

Diagrams illustrating Magnetic Flow.

the induction appears to circulate through the iron of the ring without there being any "field" outside, as shown Fig. 135, where the dotted circle *cc* indicates the magnetic flow; and it will not attract any foreign magnetic body. But now let the ring be severed on one side, and the two ends drawn apart, so as to approximate the shape of a horse-shoe, as illustrated Fig. 136. We then find that the induction has apparently flown to the surface of the iron at the two ends, and, if possible, it will leap the gap between the ends, so as to continue its circulation. One of these ends will be north and the other south; and the nearer they are to each other, the greater will be the number of induction lines crossing between them. If, again, the ring be opened out into a more or less straight bar, the magnetism will still be at the ends (Fig. 137), forming north and south poles; but the magnetism will now be what is termed "free" magnetism and will resemble static electricity, positive and negative, at either end. It is at this point, however, that the similitude of magnetism to electricity fails. For, whereas a charge of the latter can be drawn off by the contact or near approach of another body, magnetism cannot so be caused to discharge itself; and however much a piece of magnetised iron or steel may be put

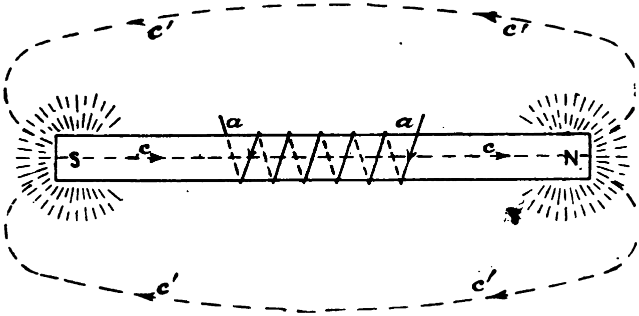

FIG. 137.—Diagram illustrating "Free" Magnetism.

in contact with other bodies of iron or steel, and may exert attractive force on them, its own magnetism nevertheless remains. It may be noted, however, that a *circulation* of "lines of force" is still maintained, through space, or air, or other non-magnetic matter, as indicated by the dotted lines *c′c′*, Fig. 137.

Returning to the horseshoe, it is further known that if the gap or field is bridged by a bar of iron or steel placed across, as depicted, Fig. 138 (*d*), the induction lines will crowd through it, finding thereby an easier passage than through air, owing to the high magnetic permeability of those metals. There will be less "free" magnetism, and the induction keeping more within the metal, the field will be reduced to a minimum. Or, again, if a shorter bar were inserted as at *d*, Fig. 139, so as just to leave very small gaps between its ends and the two poles of the magnet, then a much denser crowd of induction lines will traverse these narrow interstices, and along the intervening bar, than would be the case were the bar absent. If the inserted bar be itself a magnet, and its north pole be opposed to the south pole of the horseshoe, and its south to the north of the horseshoe, as shown in Fig. 140, the flow of induction lines will

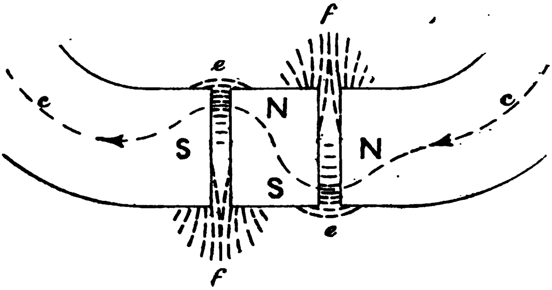

FIG. 142.—Distortion of Magnetic Flow, shown graphically.

be accelerated. On reversing the bar end for end, so that south is opposed to south, and north to north, the opposing "like" poles reduce each other, and the flow of induction lines is retarded as represented in Fig. 141. Further, if the small magnetised bar be placed in the gap with its polarity across that of the field, as shown in Fig. 142 (representing the same gap as before, but to a larger scale), we then find that the main flow of induction is diverted, and so passes through those regions of the small interstices, as at *e e*, where unlike poles are opposed, but evinces a tendency to escape as "free" magnetism where like poles are opposed, as at *f f*.

Fig. 143 may now, however, engage our attention. We discover here the same conditions as in the last diagram;

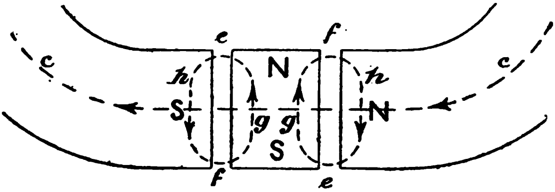

FIG. 143.—Distortion of Magnetic Flow, shown analytically.

but the magnetic flow is represented differently. Fig. 142 indicated the *resultant* or *ultimate* flow. But in the diagram now before us this ultimate flow is analysed. It will thus be noted that there are here shown three separate circuits. Of these, the dotted line *c c* indicates the main induction of the whole ring; and there are two small magnetic circuits, *e h f g*, which appertain to the polarity of the small inserted block, and are due to the iron on either side. Observing now the various *directions* of magnetic flow, as denoted by the arrowheads, we may perceive that at the regions *f f* the direction of flow in the small circuits is contrary to that of the main induction, while at *e e* there is confluence of induction. Hence in the latter regions the lines gather together and become dense, each induction assisting the other; but at the former, the main flow is baulked, and there is escape of free magnetism, as intimated. It may be remarked here that in Fig. 140 "forward-induction" is represented; in Fig. 141, "back-induction"; and in Figs. 142 and 143 likewise "cross-induction" is illustrated, in which respect these diagrams may be compared with Figs. 130 to 132 in the last chapter.

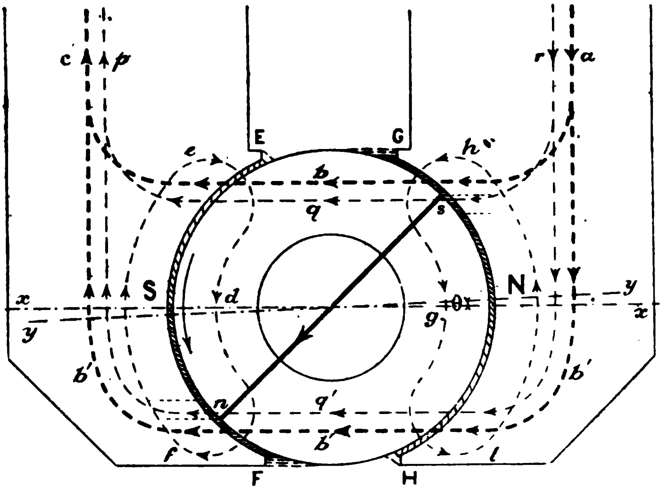

FIG. 144.—Armature Reactions shown analytically: Negative Lead and Forward-induction.

We may now proceed to the consideration of the diagrams, Figs. 144 and 145. These show once more an armature revolving in a field. In the former the brushes are represented with negative lead, thus giving rise to forward-induction; and in the latter they have positive lead, with consequent back-induction. The thick line *s n* indicates the armature self-polarity as heretofore.

Examining these diagrams now more closely, and comparing them with Figs. 130 to 132 and 140 to 143, we observe that the self-polarity sn is resolved into its two component inductions, and we find that the *cross*-induction is represented as having two magnetic circuits def and ghl, similar to those in Fig. 143; and the forward and back-inductions are represented by the lines pqr and $pq'r$. The main induction of the field is indicated by the thick lines abc and $ab'c$. It will thus be observed that the inductions parallel with the field divide, so

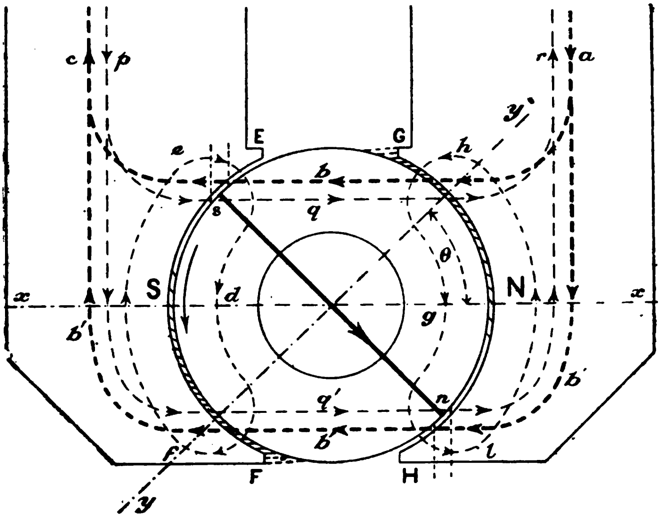

Fig. 145.—Armature Reactions shown analytically: Positive Lead and Back-induction.

that they flow partly through the upper, and partly through the lower, half of the armature. Were the brushes to be without lead, and placed exactly top and bottom, there would then, of course, be neither forward nor back-induction. But with lead assumed, the presence of these inductions needs to be taken into account.

A point that may be remarked here is that the strength of any magnetic flow is measured by the *number* of imaginary lines of magnetism that may flow together through any given sectional area of metal, matter, or space—in other words, by their *density*. Moreover, inasmuch as in Fig. 129 we assumed that the armature self-excited poles were equal in strength to the horns they opposed, and so counteracted them, we may take the same assumption here. Hence, in Fig. 145 the horns E and H may also be regarded as being counteracted by the opposing *s* and *n* armature poles; and, consequently, that the *density* of the magnetic lines issuing from *n*, equals the density of those that would be issuing from the horn H; and the two opposing densities of *s* and E would also be equal.

We may now consider the various directions of magnetic flow in these latter diagrams. Thus, at the outset, it is to be observed that in Fig. 144 the inductions *a b c*, *a b′ c*, and *r q p*, *r q′ p*, are all shown confluent with one another through the magnets, field and armature, concomitant with the negative lead to the brushes; whereas, in Fig. 145, the field-inductions *a b c*, *a b′ c*, are shown opposed throughout to *p q r* and *p q′ r*, in accordance with the positive lead. But it has to be noted in Fig. 145, that of the three lines of flow through the horn H, and with the assumptions as above, the strength of *p q′ r* plus that of *g l h* will together equal the strength of the counter-flowing magnetism represented by the line *a b′ c*. It will be convenient if we further assume that *g l h* and *p q′ r* are each respectively half of the back and cross-inductions, and are equal to each other; hence, either one of them will equal half *a b′ c*, which latter is itself half of the main induction.

Having regard now to horn G in the same diagram (Fig. 145), it will be perceived here that the cross and back-inductions *g l h* and *p q r* oppose each other, and being equal, they thus eliminate each other's flow. Consequently, the half-field induction *a b c* is alone left. We hence find that, inasmuch as there is no flow either way through the horn H, the difference in strength between this horn and the horn G may be said to be infinite. But, of course, with other assumptions, if for instance the back-induction were not so strong as just supposed, then the field-induction flowing from the horn H would not be so equally opposed, and H would not be quite counteracted; and though some of the cross-induction would now be left to assist the field-induction in horn G, and so cause this horn to be stronger than above supposed, yet the horn H having now *some* strength, the difference in strength between the two horns would no longer be infinite.

Reverting now, however, to Fig. 144, we find that at the horn H—similarly to the first assumption in G, Fig. 145—the forward and cross-inductions oppose each other, thus leaving the half-field induction flow *a b′ c*. At horn G, on the other hand, all three inductions are confluent. Thus, beside the fact that in Fig. 144 neither horn is counteracted, the point now to be noted is that, whereas the difference in strength, on the first assumptions, between the horns G and H in Fig. 145 was infinite, in Fig. 144 G is merely twice the strength of H. Hence, in Fig. 144 the field is not so distorted, nor the angle θ so wide open, as in Fig. 145. If the brushes are moved to the middle positions, so that neither back or forward-induction exist, we then find that, with the same assumptions of strength, the horn G will be three times the strength of H; and the line *y y*, representing the distortion of the field, will occupy a position intermediate in its inclination between the two extremes depicted.

In the necks of the pole-pieces on the line *x x* much difference of effect in the various cases will be observed. Thus in Fig. 144, with the negative lead, we perceive that in the **N** pole-piece the armature reactions oppose each other, thereby leaving the field-induction to flow alone; but in the **S** pole-piece, on the other hand, all the inductions are confluent. On the line *x x*, Fig. 145, we find that as the armature reactions in the **N** pole-piece both oppose the field-induction, and are together assumed equal to the latter, there will here be no flow at all: and in the **S** pole-piece the field-induction will flow alone.

It needs to be well understood, however, that in these oppositions of flow, absolute elimination of magnetism does not occur. For it is only in the sense that the magnetic induction approaches the nature of a *current* that such flow may be stopped. The magnetism still remains, but, as intimated in connection with Fig. 142 (*f f*), it becomes "free." Hence experimentally in practice, the lower end of the **N** pole-piece in Fig. 145 would be found to attract foreign bodies of iron or steel much more powerfully than would the **S** pole-piece in Fig. 144, where the induction has an unopposed *internal flow*, and consequently does not become "free."

Now magnetism at a south pole becomes free just as much as at a north pole, as shown Fig. 137. Hence we observe that in Fig. 145, the armature self-magnetisation being opposed *en bloc* at both the *s* and *n* poles, the *whole* of this also tends to become free. In Fig. 144 the contrary holds good; and we find that the self-magnetisation of the armature has an unimpeded flow in and out of the pole-pieces. The proportionate flow of lines of magnetic force between the pole-pieces and the armature is represented by the small lines crossing the intervening air-gap. Thus, though the total amount of magnetism, so to say, may be the same in each case, yet there is much more waste by magnetism become free with the back-induction than with the forward-induction. But it is equally obvious, however, that with little or no lead to the brushes, there will be less waste by free magnetism than when there is positive lead giving rise to back-induction. The inutility of the forward-induction has already been expatiated upon in the last chapter. It will be noted that Fig. 129 depicted the ultimate results of the reactions shown more analytically in Fig. 145. This "free" magnetism forms part of what is termed the "waste field" of a dynamo. It needs to be well borne in mind, however, that, in the above remarks, the effect of the *air gaps* between the armature and pole-pieces has been *disregarded.* In actual practice the waste field is considerable; and for this the gaps are chiefly responsible. Were there *no* gaps, and the armature *core* fitted tightly between the pole-pieces, then the magnetic circuit within the magnets and armature would be entirely "closed," as in Fig. 135. There would be, practically, no free magnetism and, consequently, no attraction for foreign bodies of iron or steel. This latter remark, however, will apply more justly to the case represented in Fig. 144 than to that in Fig. 145. For, in the latter, the juxta-position of "like" poles at the horns E and H would cause the formation of a joint "consequent" pole at each of those regions, from whence would issue lines of free magnetism, as represented at *f f*, Fig. 142. With the presence of the gaps, the flow of main induction is retarded in the sense of its resemblance to a current, and thus causes a large proportion of it to fly to the surface and become free. Hence, as shown at *c′c′*, Fig. 137, it seeks a path from **N** to **S** through the air on all sides, thus forming "waste field" as intimated, to which that produced by the armature reactions above discussed is additional.

On May 11th, 1893, a Paper was read by Mr. W. B. Sayers before the Institution of Electrical Engineers, describing a method of armature winding by which the forward-induction may be utilised without sparking at the brushes. This may be explained with the assistance of the diagram herewith (Fig. 146). It will be observed that between the main winding *c d* of the armature and the commutator there is inserted another series of coils *u v*. These latter are termed "commutator coils" (by Mr. Sayers), and are interwound on the armature with the

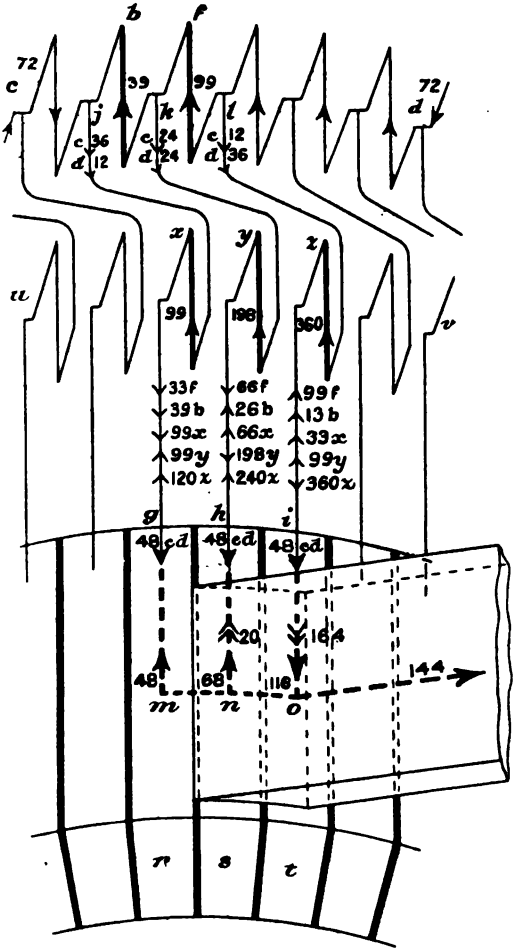

FIG. 146.—Diagram of Sayers' Armature Winding, showing sparkless running with negative lead to the brush.

main winding *c d*, although for clearness here shown separate. Put shortly, and comparing this with Fig. 118 showing the positive brush in the same position, it will be seen that by means of the "commutator coils" a resultant short-circuit current is caused to *flow out* at the lug *g*, thus baulking the main current from the armature that would otherwise be flowing *in* at *g*. The sparking such as indicated in Fig. 118 is thus obviated. Hence, with this form of winding an armature may be permitted to create its own field by inducing the necessary polarity in the pole-pieces of the field magnets, as intimated on page 224, and thus field magnet coils are not required.

It may, however, be of interest to analyse this method of winding, and its theory, more closely. Thus, an output may be assumed, as represented in the accompanying diagram, of 144 amperes up the brush, composed of 72 amperes from each half of the main winding *c* and *d* respectively. Now, the brush being at position A, Fig. 117, it will be noted that the coils toward the right at *d* and *v* are including lines of force at a greater *rate* than those to the left, and, consequently, are generating a higher E.M.F. With the same resistances in each case, larger currents will therefore be set up by the coils toward *d* and *v* than towards *c* and *u*. The numbers on the diagram all representing amperes, it will hence be observed that the coils *z*, *y*, *x*, *f*, and *b* are represented as generating currents equal to 360, 198, 99, 99, and 39 amperes respectively. It will be noted, however, that these are respectively only currents that *would* circulate were there *no opposing currents* in the same circuits—as was also the case in Figs. 118 to 121. All these five coils are short-circuited by the brush; and it has to be observed that here also the conditions depicted are those that *are broken* by the recession of the segment *r* from the brush, and so are not the results of the recession. The analysis of the effects may now be accomplished by considering in detail the course pursued by the current from each short-circuited coil individually and in order; after which the mutual effects of these various currents one on the other may be observed, and the result noted. On the lugs *g*, *h*, and *i* are thus denoted by the arrowheads, numerals, and letters, the currents which will be *tending* to flow in them from each of the five coils respectively. The 99 amperes at coil *f*, for instance, leaving at *k* and needing to return at *l*, has two paths which it may pursue, namely, *b j x g m n o i z l* and *k y h n o i z l*. In the former, the resistances of the coils *b*, *x*, and *z* have to be overcome, but in the latter only that of *y* and *z* (neglecting the resistance of the intermediate conductors). Coil *z* being common to both paths, we find that the current will divide itself between these two paths inversely according to their resistances—that is, as two to one (*see* page 171). Hence, in the path wherein the resistance of the two coils *b* and *x* is encountered we find only 33*f* amperes will flow down, and where the one coil *y* is encountered 66*f* will flow; while the undivided current of 99*f* will outflow, on its return to the negative end of coil *f*, through lug *i*. The current from *b* being analysed in the same manner, we perceive that while the whole 39 *b* descends through lug *g*, this will rise in currents of 26 and 13 amperes respectively in *h* and *i*. So also will the other currents divide and flow, as indicated; and it will be noted that the 198 amperes from coil *y*, having return paths right and left of equal resistance, returns in two equal currents of 99 *y* each. Cancelling now all opposing short-circuit currents, we ascertain, as indicated at *m n o*, that a resultant 48 amperes of short-circuit current will tend to outflow through lug *g*; and similarly, 68 amperes through *h*; while 116 amperes will *enter* through *i*; and $116 = 68 + 48$.

But to consider now the main armature currents *c* and *d*, we observe that 72 *c* amperes will arrive at *j*, and 72 at *l*. Each of these currents will have *three* paths to the brush (up to the moment of recession), passing through *x*, *y* and *z* respectively, of which paths consequently the resistances will be as one, two and three. The *c* current, for instance, will encounter in one path the resistance of coil *x* only; in the second path that of *b* and *y*; and in the third path that of *b*, *f* and *z*. We thus perceive that the main currents will divide themselves through these three paths in the proportions denoted at *j*, *k* and *l*. These form totals of 48 amperes each, as indicated below the points *g*, *h* and *i*. But in *g* we now find that the 48 *c d* current is met by the opposing 48 short-circuit current. Hence, at the moment of recession, there will be no current whatever flowing in the path *m g x j*, and so no sparking. In *h* we observe that a difference of 20 amperes will outflow, as indicated; but in lug *i* the 48 *c d* will *augment* the confluent short-circuit 116, forming a total of 164. This latter thus divides at *o*, sending the 144 up the brush, leaving the 20 to flow in the circuit *n h y f z o*; and the double arrowheads will indicate the currents that will actually and ultimately be flowing in the circuits.

It will thus be remarked that by the process of *assimilation of currents* (*see* pp. 168, 169, 192, especially the latter) the action of the resultant short-circuit current due to the electromotive forces of the short-circuited commutator coils has the effect of *diverting* the flow of current from the point to the heel of the brush, as in Figs. 119 and 121, such effect being, in fact, almost entirely due to the hindmost coil *z*.

With regard to the potential, inasmuch as the coils *x*, *y*, and *z* are in series between the main winding *c d* and the resistance of the outer circuit, then (as pointed out on pp. 180, 181) their electromotive forces will accumulate with, and become added to, the E.M.F. of the main winding. Further, it will be noted, that taken separately, coil *z* will *generate* a higher E.M.F. than *y*, and *y* than *x*. But in the commutator, apart from the effect of the "commutator coils," the M M plane being toward *c* and *u*, segment *r* will have a higher accumulated E.M.F. than *s*, and *s* than *t*. It will thus be observed that the commutator coil *x* of least potential is in series with the segment *r* of greatest potential; and inversely the highest charged commutator coil *z* is in series with the lowest charged segment *t*. The potentials of the commutator coils, added to the potentials of the segments, thus tend to equalise the latter in this respect. Hence concomitant with the absence of current flow between *n* and *m*, segments *r* and *s* may be assumed of equal potential. But, as represented in the diagram, it may be assumed that the E.M.F. from *z* has made segment *t* of slightly higher E.M.F. than *s*, as would be concomitant with the small current of 20 amperes flowing from *o* to *n*, and up *n h*. If *y* generated a higher E.M.F. than here imagined, it would impel a larger short-circuit current. So that with the increase of E.M.F. of *s* over *r*, there would also be a flow of current from *n* to *m*, and consequent back-sparking at the moment of recession. This would occur, it will be perceived, if the negative lead to the brush were increased. Contrariwise, *less* negative lead, by letting the proportional E.M.F. of *y* drop, will cause forward-sparking. With regard to these short-circuit currents, the 360 amperes in coil *z*, the 198 in *y*, 99 in *x*, 99 in *f*, and 39 in *b*, it has to be noted that the products of these and the electromotive forces of their respective coils, that is, the E.M.F. *generated in each coil at the moment of short-circuiting*—not the total absolute E.M.F. of the machine—will represent a certain amount of *lost energy*. This, however, does not necessarily mean energy that has been created and then lost by being *misspent*. For it is rather a loss by the *prevention* of the creation of energy which might otherwise be added to the total efficiency of the machine, but here is not added.

This point may be made clearer. Reference to Fig. 118 (p. 185) will show how the forward-sparking that occurs with ordinary drum or Gramme winding, when the brushes have negative lead, is due to the breaking, not only of the main current, but also of short-circuit current. Reverting to the diagram accompanying these remarks, it will be seen that, besides the main current of 48 amperes entering at *g*, there are also the short-circuit currents, in part or wholly, from the coils *f*, *b*, and *x*, also entering by lug *g*, forming a total much larger than the main current alone, similar to the case in Fig. 118. It is thus this whole total, in the case assumed $33f + 39b + 99x + 48cd = 219$ amperes, that has to be prevented from entering through lug *g*, which is accomplished by a counter-current of the same quantity.

Argument might be adduced that as these opposing currents prevent each other's flow, therefore the energy of which they would otherwise form factors is not spent. But, as intimated, this is not the point. Analogy to the case may be found thus. If two steam engines, with full steam turned on, are geared together so that each prevents the other's motion, *no work is done, and so no energy is spent.* Or, again, if two dynamos be coupled up, positive to positive and negative to negative, on being run, their currents will oppose, and so baulk each other; and if their outputs are equal, no current at all will flow; and so, here again, no work will be done. But the point now is that, with both the engines and the dynamos, these being rendered in each case assumed mutually *inoperative*, they represent so much capital outlay lying practically idle, and producing no dividends. It is thus that the *loss* due to all the opposition of currents in this winding may be viewed and estimated; for we find here, that the products of these currents and their several electromotive forces represent so many watts of *power* opposed to *power*, which, for *want of motion*, mutually prevented, is not converted into energy or work, which might otherwise become added to the general efficiency of the machine. This loss, in fact, may be regarded as the price of the sparklessness attained by this arrangement of winding, to be put against its various advantages, such as the non-requirement for coils on the field-magnets.

CHAPTER XXV.

SPARKING AT COMMUTATORS.—ARMATURE REACTIONS: FIELD ASYMMETRICAL.*

Having thus far discussed the subject and theory of magnetic flow, we may now proceed with our general disquisition into the causes of sparking, in which our last chapter was somewhat of the nature of an interpolation. The source of sparking we propose now to consider was among those mentioned at the commencement of Chapter XXIII., and we allude to a want of symmetry, or *asymmetry*, in the field—that is, a field stronger in one half than in the other half; or, in other words, having regions on the opposite ends of any diameter which are not of equal strength. It is in this direction, therefore, that we may find that particular method of investigating the reactions of an armature in the field, illustrated and described in our last chapter, to be essentially of service.

The case of a field excited by four magnets in parallel, as illustrated Fig. 147 herewith, affords an example wherein such absence of symmetry might be produced, by one coil not developing its full exciting power, owing, perhaps, to a bad joint. Thus one side of the field would have fewer lines of force than the other.

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* This and the chapter preceding are based largely on a Paper read by Mr. Jas. Swinburne before the Institution of Electrical Engineers, and published in *The Electrician*, Vol. XXIV., 1890. (*See* Feb. 14th, pp. 374-375 for particular portion to which reference is made.)

But in all cases of an asymmetrical field, it may be remarked, a drum winding will be less affected by this manner of fault than a Gramme. For the coils of the former embrace the whole field with all its inequalities; while two coils of the latter at opposite ends of a diameter may be traversing portions of the field unequal in strength, and so will not generate the same E.M.F.

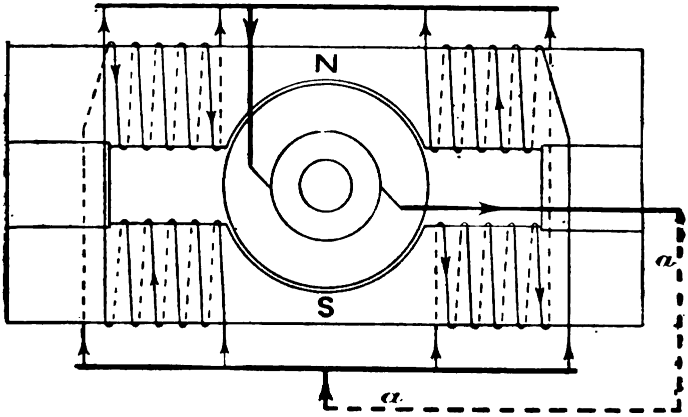


FIG. 147.—Four Magnet Windings in Parallel.

Apart from the possible cause mentioned above, however, there are two other sources from whence may arise this particular trouble, which are of a nature, perhaps, not quite so evident. To explain these, reference may be made to Figs. 148, 149 and 150. In the two former of these diagrams it will be observed that the neck of the pole-piece, as on *x x*, is only half the section of what it is higher up, as at *t t*; while in the latter, the section on *x x* is considerably less than half that above. Thus, in the last case, we find an asymmetrical field may be caused simply by the fact that, of the lines of induction descending, say, through *t t*, the half of the induction lines required for the lower part of the field have not room to pass down through the section *v v*, and to rise again through *w w*. The lines are choked or throttled in the necks of the pole-pieces. Hence the upper part of the field will be stronger than the lower part.

But, before further discussing this latter diagram, which we must leave for the present, it will be better to consider Fig. 148. This shows a field and armature similar to those in the last chapter; and it will be observed that, in like manner, three magnetic circuits are indicated respectively by *a b b′ c*, *d e f*, and *g h l*, representing the main and cross-inductions. The brushes are shown touching in the vertical centre line, so as to preclude any back or forward-induction; for either of these latter, if present, would be merely a superadded effect, not necessary for the present argument. The direction of the flow in the three circuits will be as indicated by the arrowheads; and it will be noted that, as in foregoing diagrams, in **S** the cross-induction flow from *f* to *e*, and the main-induction from *b′* to *c*, are confluent; and in **N** the inductions from *a* to *b′* and *l* to *h* oppose each other. Similar confluence will be observed at the horns G and F, and opposition at the horns E and H.

Now a field may be wanting in symmetry, yet without being absolutely weak. There may be plenty of exciting power in the magnet coils, but the results are not equally distributed through the field. For our present purpose, however, it will be convenient to assume that the field before us is weak as well as asymmetrical, so that the effects it is our object to render evident may be the more conspicuous.

A field may be rendered weak by two causes. These may be either that the magnets are too small, or else that the field-magnets are not sufficiently excited, owing to a deficiency of ampere turns in their coils. In the former case the magnets and pole-pieces may be carrying all the induction lines possible, or in other words, they may be "saturated;" but in the latter case they will not be saturated.

Of these two causes, hence the former may be assumed to be the case in Fig. 148; and consequently it is understood that both the magnets and pole-pieces are saturated. It should be noted, however, that this means that these parts are saturated by the *main* induction along *a b b′ c alone.* We have now to

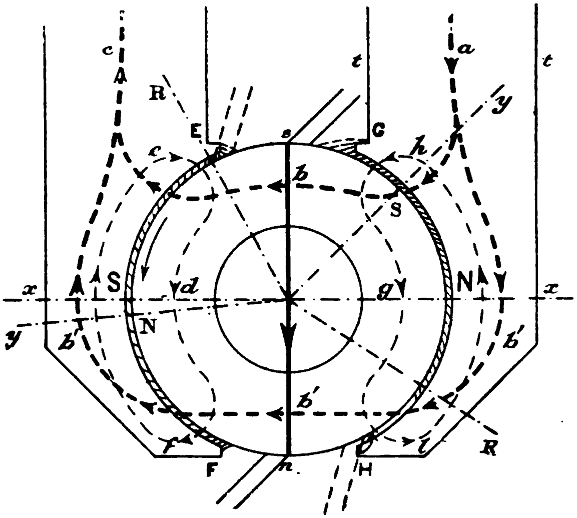


Fig. 148.—Asymmetry of Field due to Throttling of Cross-induction. Sparking at one Brush only.

consider the superimposed effects of the cross-induction, indicated by the smaller circuits *g h l* and *d e f*.

In the first place, it needs to be observed that, inasmuch as *s n* is vertical, the opposition of the armature self-excited poles to the horns E and H will not be so direct as in the case represented in Fig. 145. Back-induction being absent, we may in fact adopt the exaggerated assumption, with the assumption of a weak field, that the cross-induction is by itself equal to the field-induction. Thus now to direct our attention to these cross-inductions, we observe in the first place that these particular reactions of the armature do not strengthen the field, but that rather they are the direct cause of its *distortion*. For in so far as these magnetic inductions may be regarded as *currents*, it will become palpable on reflection that these cross-induction flows will merely act on the main induction flow in much the same manner as on an earlier page we demonstrated that the short-circuit currents at the commutator took effect on the main current, namely, that they *diverted* the flow of the main current from one course to another. Thus it is in the case before us. We find that the effect or tendency of the *g h l* induction is to *transfer the exit* of the main induction from **N** as much as possible from the bottom to the top of the field;

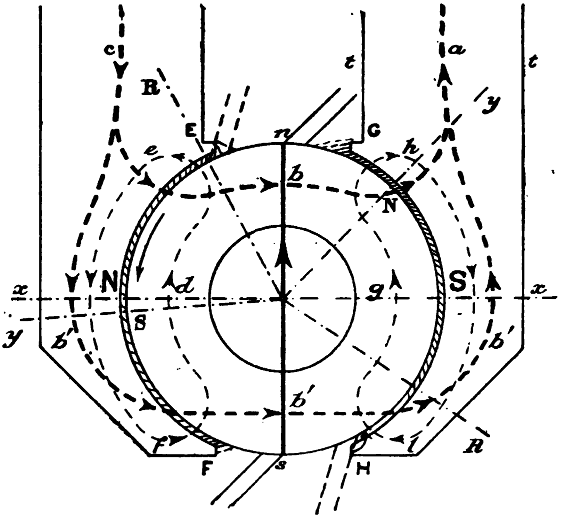


FIG. 149.—The same as previous diagram, but with Polarities reversed. Sparking at one Brush only.

and the tendency of the *d e f* induction is to *transfer the entry* of the main induction into **S** from the top to the bottom; and, as illustrated by the dotted lines in Fig. 129, the whole body of induction lines leaving **N** will now crowd out as much as possible toward the horn G, and passing through the upper and lower halves of the armature, will thus *tend* to impinge for the most part on the lower half of the pole-piece **S**.

It will be noted, however, that though the cross-induction may have this diverting effect on the main flow, it nevertheless does *not augment* the latter through the armature and field. The flow down *g*, for instance, will merely equal the strength of the cross-induction; and the strength along *b'* will continue to be just that of half the main induction; and the flow through the horn H will be the difference between that at *g* and *b'*, here assumed as nothing.

But it is evident, referring again to the short-circuit currents at the brushes, that if the lugs, for instance, were not large enough to carry an augmentation of main and short-circuit current, the latter could not take effect—its very existence in fact being imperilled. Thus it is in the case before us. For we find that the cross-induction from *f* to *e* *plus* half the normal main inductions are wanting to ascend through the section on *x x*. But the latter induction alone, under the circumstances, saturates this section; therefore, there is not room for both inductions to pass. Consequently, excepting in so far as **S** may become super-saturated, the *d e f* induction cannot have the effect in diverting the entry of main induction into **S** from E towards F that it would otherwise have. Hence we find that the entry of main induction into **S** will extend in area much more fully towards E, than its exit from **N** extends toward H.

The upshot, therefore, as may be perceived, is that the field is rendered asymmetrical. For in the first place, as the induction lines will leave **N** in the regions towards G in a dense condition, but cannot correspondingly enter densely the regions of **S** toward F, these diametrically opposite parts of the field are unequal in strength; and secondly, as already explained, lines are passing between the armature core and **S** quite up to E, but not between the core and **N** toward H; and *consequently the horn* E *is not counteracted like the horn* H.

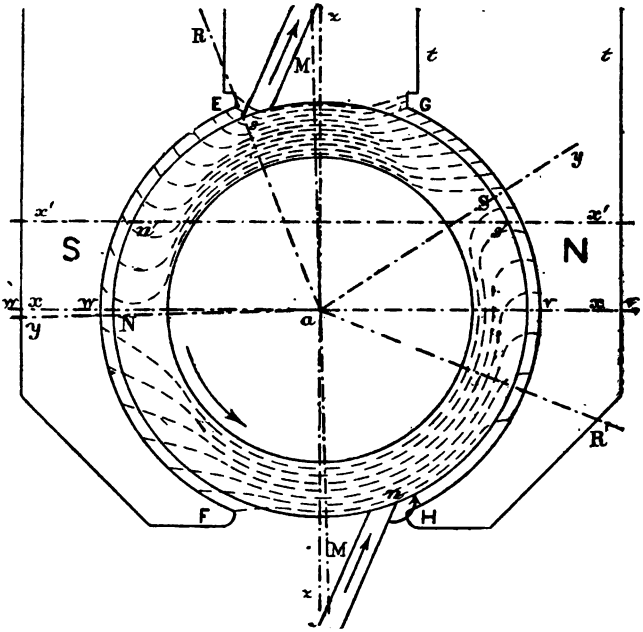


FIG. 150.—Asymmetry of Field due to Throttling of *Main* and Cross-induction. Sparking at one Brush only.

Further effects are now to be observed. Inasmuch as the lines are entering the armature more thickly toward the horn G, than they are leaving it toward F; and the outflow is more evenly spread on the side toward **S**; therefore, the ultimate pole S of the armature is higher above *x x* than the N pole is below it; and the centre line of distortion *y y* will be seen to be deflected through the axis as shown.

Moreover, as the lines of force between the pole-piece and armature are denser toward E than H, it is obvious that the RR plane above will not be so far forward as that below. Hence the upper brush will not require so much lead to attain a non-sparking position as the lower brush; and it will not be possible, with the brush points diametrically opposite each other, for the brushes both to be in non-sparking positions at once. It will be observed, however, that this deflection of the RR plane refers only to Gramme winding. For it is obvious that with a drum winding, wherewith each coil embraces the whole field, some one angular position in one plane through the axis will be found where the requisite reversal takes place.

Now we have remarked that when lines of magnetic induction cannot find a circuit, as at the two ends of a bar, the magnetism will fly to the surface at the ends, and become "free" magnetism radiating into space. Thus, continuing to refer to Fig. 148, we perceive that as of the combined inductions *b′* and *d* flowing to meet each other, all cannot pass up through the neck of **S**, a remainder, equal to the *d* cross-induction, will be left without a circuit. This remainder will, therefore, become "free." It may be said in fact that the *d* cross-induction, finding no circuit, but yet not being eliminated, becomes free at both ends, above and below. At the horn G both the main and cross-inductions are flowing unimpeded, so that neither becomes free. But at F, on the other hand, where the inductions oppose each other, *both* become free, their difference alone, if any, remaining as an internal flow. These remarks of course, it will be observed, are made without reference to the air-gap between the armature and pole-pieces, alluded to in the last chapter, as this would not affect the present argument.

Fig. 149 is merely a reproduction of the last diagram, but with all the polarities reversed. It will be seen, however, that though the inductions are reversed, yet their confluences and oppositions of flow are in the same locations as in the foregoing case, and, consequently, the lower brush will still require the most lead.

Reverting to the question of the free or waste magnetism, it will be observed that in both these diagrams, Figs. 148 and 149, this effect occurs at the horns E, F, and H, but not at G (neglecting the effect of the gap). There is thus a want of symmetry in the waste field produced, concomitant with the want of symmetry in the field proper. In these cases we have, of course, as intimated, assumed a main induction of exaggerated weakness, at least in respect of the horn H. With a main induction *a b′* considerably stronger than the cross-induction *g l*, as would be usual in practice, their difference would continue along *b′ c*; while the remainder, that is, *g l*, and a part of *a b′* equal to *g l*, would become free, and so form waste field seeking an air circuit to **S**. This will apply also to the horn E, where there is likewise opposition of flow.

Now all the above results, it will be perceived, are simply due to a want of section in the necks of the pole-pieces—or rather, of *one* pole-piece, as at **S**, Fig. 148, so as to enable it to carry both the main and cross-inductions. In Fig. 129, it may be assumed that the pole-pieces are not thus wanting in dimensions, and that, therefore, there will be no choking or throttling of cross-induction in the neck, and so no asymmetry; and the weakness of field in that case will be attributable to a deficiency of exciting power in the coils of the field magnets.

At the commencement of this chapter we alluded to an asymmetry of field that might be caused by the throttling of the main-induction itself in the necks of the pole-pieces. We thus find an example of this in Fig. 150. For, as previously pointed out, the sections here at *w w* and *v v* are less than half that at *t t*, and consequently are unable to pass the full number of induction lines—that is, half the total number—to the lower portion of the field.

Now, it is assumed in this case that there is no deficiency of strength, at least in the upper half of the field, and that, therefore, there is no falling away of main induction under the horn E, as in the foregoing cases. But, inasmuch as the lower part is weak, the line $x\,x$ will cease to represent the centre plane of the magnetic lines of the field; and this plane will now be higher up, as shown at $x'\,x'$. The tendency of the field will consequently be for the pole-pieces to induce poles on the armature which shall both be on the line $x'\,x'$, south on the right and north on the left, as indicated by s' and n'; and a resultant polarity will eventuate between n and n' at N, and between s and s' at S.

We thus find again, in the instance of the Gramme ring here depicted, that $y\,y$ becomes deflected through the centre at a; and that, owing to the induction path through the upper part of the armature becoming much shorter than that through the lower part, the magnetic resistance of the upper will be much less than that of the lower path, and consequently, as shown, the induction lines through the armature will be more dense above than below.

Moreover, as there is no absence of induction under the horn E, we note that the core will commence parting with lines, and the coils will commence excluding lines, on their arrival at this point. Hence we may assume the upper R R plane to be where indicated by the line R a; and the upper brush, being given that amount of lead, will not spark.

Having regard now to the horn H, this is normally weak, owing to insufficiency of main induction. It may thus be assumed to be counteracted by the self-excited n pole of the armature. There will, consequently, be a falling away of induction for some degrees above H, and lines may not commence entering the core from N till about where shown in the diagram. Thus the lower R R plane will come at or about a R′; and the lower brush, as in the other cases of asymmetry already discussed, will require more lead than the upper brush; and though the upper may not spark, the lower brush will spark persistently.

We thus discover how an asymmetrical field may be produced by the throttling of the main induction. The cause now described may, of course, operate simultaneously with that previously discussed. It is to be noted, however, as already remarked, that all asymmetry such as we have so far touched on, can be prevented in single horseshoe magnets, by simply making the pole-pieces of sufficient section in the necks to carry all the induction.

Before closing this chapter some remarks may be added concerning the cross-induction with double-ended magnets, as shown Fig. 147; for the conditions here are not quite the same as with the single horseshoe magnets we have usually assumed. Fig. 151 is thus a reproduction of part of the latter diagram, showing the field and armature only. The lines *a b c* and *a′ b′ c′* indicate the two main inductions, one from each horseshoe, and the circuits *d e f g* and *h i j k* represent the cross-induction.

It will now be observed, in the first instance, that there is no normal flow of main induction through the necks at **N** and **S**, and that, further, the necks are of appreciable thickness. Consequently, both cross-inductions have an unimpeded course, and they will both be able to exercise their full effect in diverting the main-inductions, and so in distorting the field; though, being the same on both sides, they will not produce any asymmetry. For by a process somewhat analogous to what on a previous page, when discussing electric currents, we termed *assimilation*, it will be evident that the *a′ b′ c′* flow, being opposed in the horn E by the *d e f g* induction, will become diverted, and will flow in the *d e f g* circuit. In like manner, some of the *a b c* main induction will become assimilated in the *h i j k* circuit. It will, however, be of course understood that this view of the subject is only permissible within the limits of the extent to which magnetic flow may be regarded as a *current*. Outside these limits it will be noted that there will be an escape of free magnetism at the horns E and H, where the inductions are opposed, and these latter horns will be weakened, while the horns F and G, owing to the confluence of the inductions through them, will be strengthened.

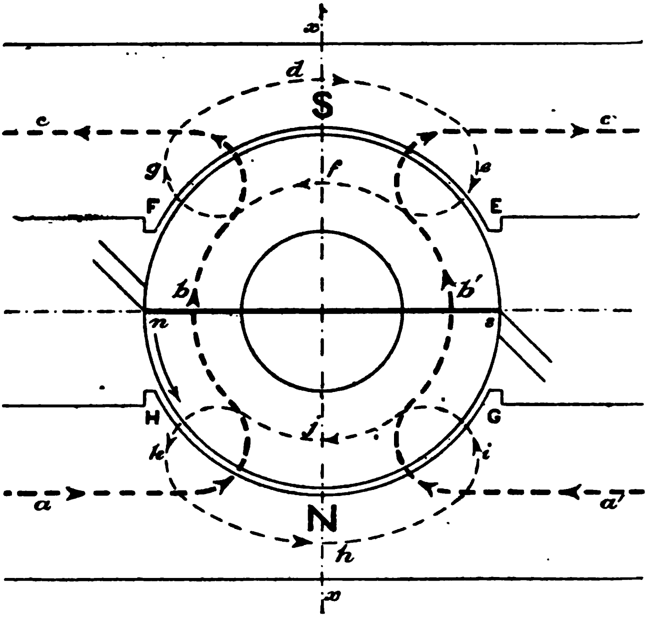


Fig. 151.—Four-magnet Field, with *Cross*-induction.

But we may now consider Fig. 152. Here the necks at S and N have been reduced, the effect of which is to impede the flow of cross-induction. A slight flow of that reaction may take place, but this may be disregarded. All armature reactions, however, are not eliminated. For a result of the suppression of the *cross*-induction *per se*, is that this induction on either side is now, as it were, divided into two smaller *oblique*-inductions, as indicated by the circuits $d\ e\ f$; and whereas the line $x\ x$ represented the equator of the polarities of the *cross*-inductions, we now find that the two inclined lines $x'\ x'$ and $x''\ x''$ will represent the equators of the polarities of these smaller *oblique*-inductions; and the latter will, in fact, be the outcome of the armature coils that are in the planes quite or about parallel respectively with $x'\ x'$ and $x''\ x''$.

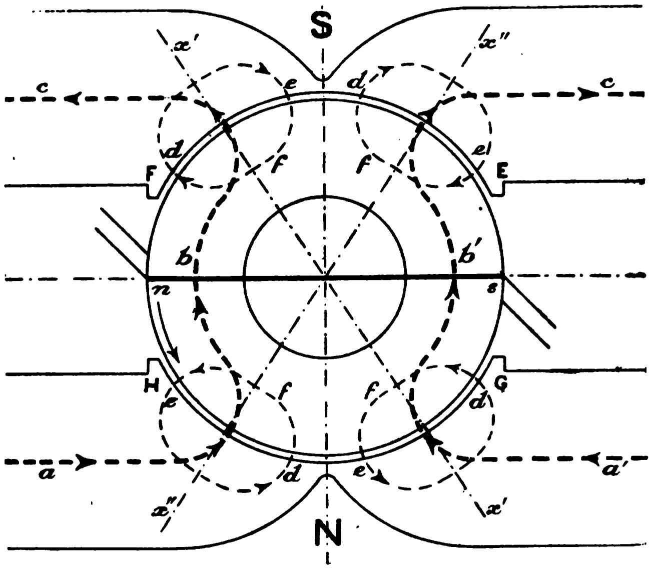
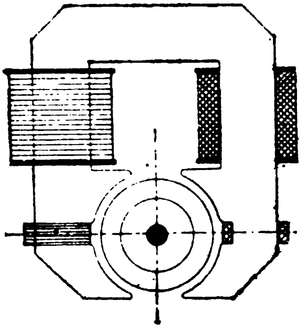


Fig. 152.—Four-magnet Field, with *Oblique*-induction.

Inspection will now make it evident that at all the points $e\ e$ there is opposition of flow, and at $d\ d$ confluence of the main and oblique-inductions. Hence the ultimate flow will be denser than normal towards the points $d\ d$, and less dense towards $e\ e$; and at these latter regions free magnetism will escape. It will be observed that the horns E and H are weakened, and F and G strengthened, as in the last diagram. But, inasmuch as the induction in any one of these small oblique circuits is the outcome of a smaller number of armature coils than would be the case with the cross-induction proper, an oblique-induction will not be able to exercise such an effect in diverting the main flow as the cross-induction would be able to exercise. Hence we find that the horns E and H in Fig. 152 will not be so weakened, nor the horns F and G so strengthened, as in the case represented, Fig. 151; and, other things being equal, the distortion will also be lessened, so that not so much lead will be required for the brushes to attain absence of sparking.

These later remarks are suggested by the discussions on Papers read before the Institution of Electrical Engineers by Mr. W. B. Esson and Mr. Jas. Swinburne, to the last of which reference was made in the foot-note on page 243. See *The Electrician*, Vol. XXIV., pp. 526–527, and more especially observations made by Prof. George Forbes.

On the subject of obviating armature reactions, attention may be called to an abstract from an Article or Paper by Mr. J. Fischer-Hinnen in *The Electrician* for May 26, 1893, pp. 104 to 107. In a diagram accompanying this article, a method of counteracting the flow of cross-induction in the necks of the pole-pieces is illustrated. By means of small coils surrounding the necks, a counterflow of induction is set up which baulks that of the cross-induction. Thus the distortion of the field is minimised; and little lead is required for the brushes, which may consequently rest nearly or quite in the plane of maximum E.M.F. without sparking.



CHAPTER XXVI.

SPARKING AT COMMUTATORS.—ARMATURE DEFECTS.

We may now proceed to the consideration of further sources of sparking at the brushes on a commutator, differing materially from those hitherto discussed. These, though still inherent to the machine, are yet scarcely to be included within the general scope and meaning of the term "armature reactions." For any errors under the latter heading, and trouble therefrom, are to be understood more especially as questions of calculation and design having reference to the machine as a whole; whereas, the sources of sparking we now propose to inquire into are more of the nature of purely mechanical defects, and are such as will occur in the armature only. Yet, even of these also, though many may arise in the workshop, others may have their origin in a defective design.

Now the faulty field, it will have been noted, whether too weak, or asymmetrical, or both, did yet not cause any oscillation, or lively swinging to and fro, of the normally fixed planes. We found the planes bent or deflected through the axis of rotation, or unduly inclined. But these effects were permanent and stationary; and the planes once fixed had no further normal movement. This, however, will not apply to the cases we are now about to investigate. For a fault of a local and mechanical

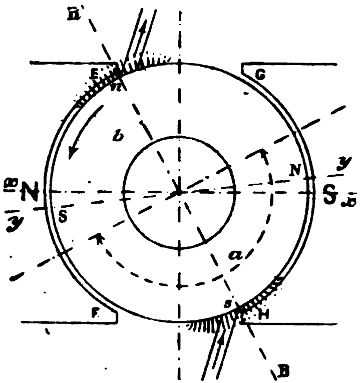


FIG. 153.

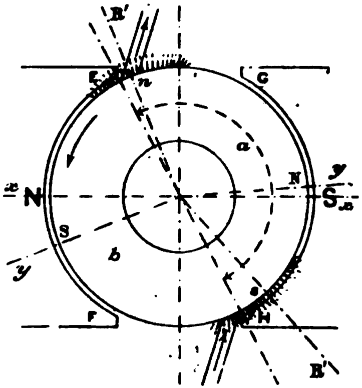


FIG. 154.

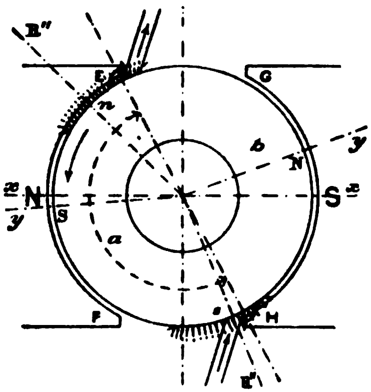


FIG. 155.

Diagrams illustrating Distortion of Self-excited Polarity of Armature, due to want of Symmetry in the Winding, with consequent Oscillation of Neutral Plane, and Sparking.

nature in a revolving armature will be ever changing in its effects within the normally stationary field. Such a fault, thus, at some instants may have no effect, and at other instants be upsetting the whole circuit inside and outside the machine. A result will be that oscillations of the normally fixed planes, or constantly changing deflection at the axis, will be ever recurring. Movements of this kind, moreover, may be steady and continuous, as the armature rotates; or they may be sharp and intermittent.

Setting aside the giving way of insulation—for this would be equivalent to a short circuit, or an "earth," discussed in a previous Chapter (XXII.)—we find these faults are divisible under two main heads, viz., *asymmetrical winding*, and *defective joints*.

To commence with the former, asymmetry, or a want of symmetry, may be produced in various ways. Edison's and Siemens' earlier methods of winding—the former illustrated Figs. 14 to 16—are examples in which symmetry was wanting, owing to the sections differing from one another in total all-round length. Where there are more than one layer of conductors along the core, either inside or outside in the case of a Gramme, conductors that should lie next the core may be in the outer layer, and *vice versâ*. Thus the total area enclosed by some of the coils will differ from that enclosed by others; and so they will generate more E.M.F. if larger, and less if smaller. A long coil or section will also offer more resistance than a short one. But the upshot may be that one-half of the winding would be generating a different output to the other half. Although the necessity for symmetry is well understood by manufacturers, it will, nevertheless, be of educational interest briefly to consider the results of its absence.

Figs. 153, 154 and 155 herewith, represent an armature, which may be either drum or Gramme wound, but of which one half, *a*, generates less E.M.F. and current than the other half, *b*.

As regards the drum, the two halves of the winding (as shown Fig. 1) being intermixed, the sketches must be taken as diagrammatic. Now in Fig. 153, where the weak and the strong half are both bisected by a straight line between the brush points as shown, the self-excited poles of the armature will also come on this line, as indicated by the letters *n* and *s*. Assuming a normally symmetrical field, the horns E and H, being equally opposed by the armature poles, will be equally reduced, and the R R plane may be represented by the line through *n* and *s* continued, and the distortion of the field will be represented by the inclination of the line *y y* to *x x*.

But with a quarter revolution we find a condition of things as illustrated Fig. 154. The ampere turns of the half *a* being weaker than those of *b*, the polarity of the latter is the more powerful, it still being understood that this refers to the *self-excited polarity* of the armature only. A one-sided polarity thus results, as indicated. The horn E, not being so directly opposed by *n*, is not sufficiently reduced, so that the short-circuited coil or coils passing it develop too much current, and back-sparking takes place. On the other hand, the horn H is opposed by *s* abnormally, and is, therefore, reduced too greatly, so that the short-circuited coils cannot generate enough current. Hence forward-sparking ensues. In other words, the R R plane is deflected for the moment into the position R′ R′. Further, we may note that as *n* is abnormally near **S**, and *s* abnormally removed from **N**, N and S both drop, and *y y* is thus deflected—that is, the field is distorted asymmetrically. Fig. 155 is a half revolution ahead of Fig. 154, and will be observed to show reverse results. It will thus be seen that as the armature rotates, the R R plane oscillates with each revolution between the two deflected positions R′ R′ and R″ R″, with consequent sparking; and it may be further observed that the rule that the self-excited polarity of the armature must follow the brushes *exactly* is here departed from, inasmuch as that rule depended on the armature being wound with perfect symmetry. The *mean* self-excited polarity will, of course, follow the brushes; and the oscillations will thus take place about this mean.

The above, however, constitutes what may be termed a mean, or resultant, effect of asymmetry in armature winding. Regarded more in detail, it is to be observed that any particular coils that may be larger or smaller than a normal size, will generate respectively too much or too little E.M.F. when short-circuited by the brush, and so will contain *too much or too little short-circuit current.* Consequently, in the former case, there will be back-sparking, and in the latter case forward-sparking (*see* Chapter XX.), the latter possibly being what we have termed "shunt sparking."

But a point to be noted is, that the asymmetry may be confined entirely to the end-winding, each coil being practically symmetrical within the field, and generating the same E.M.F.; and this view of the subject may be regarded as probably of more importance than the foregoing. For an asymmetrical end-winding, by preventing all the coils or sections from being of the same total length, will cause their resistances correspondingly to vary. Hence, the E.M.F. not changing, the short coils or sections, when short-circuited, will have generated within them a larger current than the long coils or sections—it being borne in mind that with the very small E.M.F., a very slight variation of resistance will considerably affect the quantity of short-circuit current. So there will again be alternate back- and forward-sparking at the brushes.

Our attention, however, may now be directed to that other source of sparking of a mechanical nature to which we have alluded. We refer to defective joints in the armature winding. This trouble is, of course, especially peculiar to heavy windings of which the coils are constructed of stiff bar or strip, requiring to be riveted, soldered, or otherwise jointed together, as described in our earlier chapters. A joint improperly effected through the parts not being thoroughly clean and bright, or the solder not fulfilling its purpose, or from any other cause, will offer resistance to the flow of current.

For convenience of reference, such faults due to defective joints may be divided under four heads. These are represented by the letters *w*, *x*, *y*, and *z*, in the annexed diagrams, Figs. 156 and 157, of which it will be observed that the former shows one complete heavy bar drum coil, and the latter a wire Gramme coil, with a wire drum coil dotted, while in both the commutator segment is added. A fault *w*, as will be noted, affects the flow of current into or out of one particular segment only. With regard to fault *x*, inasmuch as the bar *a b* appertains to two adjacent coils (*see* Fig. 1), this fault will affect the flow of current between the segment and *one* of these coils, of which the commencement is shown at *c*. The arrows indicate the current flow, assuming the segment to be under the positive brush. It is thus to be discerned that a fault *x* may impede the whole flow into the segment of one half of the armature current, such as we have denoted by *c* in the diagrams in Chapter XX., and yet permit a free flow of current from the half of the armature similarly denoted by the letter *d*; while, in any case, even when that particular

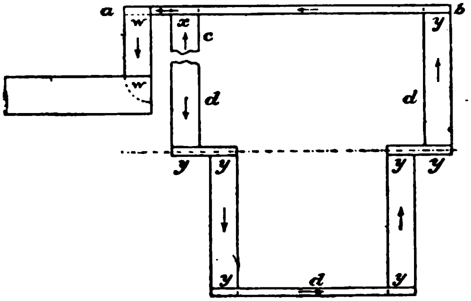


FIG. 156.—Diagram of Drum Armature Bar Coil, indicating possible Faulty Joints.

segment is not under the brush, such a fault will impede the flow of current from coil to coil within the winding. Faults *y y* retard the flow of current within the winding, thus having the latter effect of fault *x*. One such fault *x* or *y*, however, it is to be noted, can only affect *one* half of the winding and current at a time, and thus, as the armature rotates, will affect the flow on either side alternately. A fault *z* combines with all the above the additional effect that, when in series with the brush, like faults *w* or *x*, it may check the flow of current to or from *both* halves of the armature, that is, the whole flow of the main current.

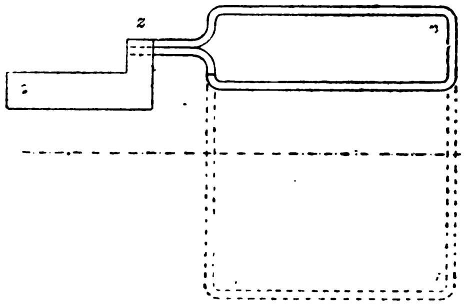


FIG. 157.—Diagram of Gramme or Drum Armature Wire Coil, indicating possible Faulty Joint.

Now any such retardation of current as above mentioned is to be regarded in two aspects. First, the effects in relation to the main current; and secondly, the results in relation to the short-circuit currents, as in the coils *b* and *f* in the diagrams in Chapters XVII. to XX. The latter results we shall discover to be of the greater consequence, as a matter of fact, in reference to sparking. For as regards the main current, it is to be noted that any of these faults taking effect will be in series with the outer circuit with all its resistance. Thus the actual resistance of a fault may be so small, that when added to the total resistance of the inner and outer circuit, its addition thereto may be nearly or quite inappreciable as regards any results produced. Yet the effect on the short-circuit currents may be considerable. In so far, however, as the main current may be affected, that is, reduced in quantity, this would cause one side of the armature to have fewer ampere turns than the other side, and so produce a distorted polarity as explained in connection with Figs. 153 to 155, with consequent sparking.

It is undoubtedly, however, the effects on the short-circuit currents that are of the greater importance. For a fault too weak to materially reduce the main current may, nevertheless, almost eliminate the short-circuit current. Thus, suppose the total resistance of a circuit, inside and outside, to be 3 ohms, while the resistance of one single armature coil is only ·0006 ohm, it is evident that a faulty joint in such a coil offering, say, ·006 ohm resistance, would only increase the total resistance to 3·006: but it would increase the total resistance of the particular coil to ·0066, or eleven times greater than normal. Hence, assuming a normal main current of 44 amperes, when the brush would be at the normal non-sparking position, each time this coil was short-circuited—taking the position lettered *b*, that is, in the diagrams in Chapters XVII. to XX.—it would be carrying only the *eleventh* part of the short-circuit current necessary for a sparkless recession of its segment from the brush, or only 4 amperes instead of 44, thus leaving a current of 40 amperes to be broken, with consequent forward sparking. The necessity, therefore, for extreme care in making the joints in a coil so that all the coils shall have a similar total resistance—or, better still, the advisability of avoiding joints as much as possible—is thus the more obvious if sparkless running is to be attained.

An additional argument is, of course, to be found here for the use of carbon brushes. For these, as was explained in Chapter XXI., are but little affected by the short-circuit currents; and, consequently, a defective joint that might cause a metal brush to spark in the manner above indicated would produce no such effect with a carbon brush.

Some further causes of sparking which may now be appended are of a more general nature. Thus any source of vibration in running a machine, such as a clumsy joint in the belt, combined with too light a shaft, or insufficiently rigid bolting down, may cause a slight jumping of the brushes, with sparking as a consequence. A further tightening of the brushes will increase the wear of both them and the commutator segments. The segments, moreover, may wear unevenly, one or more of them perhaps becoming burnt by periodical sparking (such as by a bad joint above discussed), which will then cause the brushes to jump, and so to spark yet more. It is especially important that all the brush gear should be strongly constructed, so as to hold the brushes firmly, and not to spring. With a field symmetrical as is usual, sparking may be caused by the brush points not being diametrically opposite each other, so that they cannot both be in the non-sparking plane at once, and one brush may spark and not the other. Trouble may also arise from the commutator not being kept clean and free from oil and grit. Vibration, such as may lead to sparking, may ensue from the armature being out of balance. But a further source of trouble in this direction has been found in the use of *cast* metal segments, instead of rolled metal. This has reference, however, more especially to tram-car motors, wherewith, on account of the jolting, it is necessary to keep the brush springs somewhat tight. The frictional wear is thus great; and it would appear that, owing to the cast segments not being so homogeneous, or so uniform in their hardness and quality, as rolled segments, they do not wear so evenly. Hence, with the cast segments, at least under the circumstances indicated, the commutator much sooner gets out of truth, causing the brushes to jump, with consequent sparking.

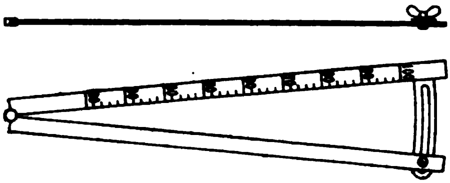
CHAPTER XXVII.

THE TAPER OF COMMUTATOR SEGMENTS.

A CLOSING chapter may here be added, having reference once more to the construction of commutators, more especially to the formation of the segments to a correct taper, so that accuracy of fit may be ensured.

When the segments or bars for a commutator are cast, instead of being rolled, they require to be machined or filed on their sides before being put together. To secure accuracy in this operation, it is necessary that the parts be worked up to a gauge. In this manner the requisite exactness in both thickness and taper may be obtained. When, on the other hand, drawn copper is used, it is equally necessary to specify the exact taper in ordering, and generally to send a gauge, sample, or template to the manufacturer.

A very useful and simple gauge or tool has been designed for this purpose by Mr. A. P. Trotter, and was adopted in 1886 by Messrs. Goolden and Trotter. This instrument is illustrated on a reduced scale, in Figs. 158 and 159 herewith. There are two ways of stating the taper for a commutator segment or strip. One is to give the angle between the sloping sides, and the other is to describe the slope of one side in relation to the other side as a gradient of "one in so many." As a circle is divided into 360 degrees, the angle for a segment is, of course, arrived at by simply dividing the 360 by the number of segments, or "parts." Thus the angle of a strip for a "40-part" commutator will be 360/40 = 9degs. But it must be noted that this assumes the parts put together *without the insulation.* This point requires attention. It has to be borne in mind that the mica or other insulation between the segments does *not* taper, but is of even thickness. Fig. 160 shows how all the strips of a commutator are made to fit in the first instance, *minus* the insulation; while Fig. 161 shows the same parts put together *with* the insulation. This latter at once increases the diameter; and it should be noted further, in this latter case, that the sides of the sections, if continued inwards, do not meet at the centre. Here, in fact, is demonstrated how great an effect on the ultimate diameter the insulation may have, especially when there are a large number of segments, and a high voltage requiring the insulation to be thick. In designing a commutator, it may be observed that



Figs. 158 and 159.

$$r = \mathrm{R} - \frac{n \times d}{2\pi},$$

where r is the inside radius of the commutator when put together without the mica, R the inside radius of the complete commutator, n the number of segments, and d the thickness of the mica or other insulation.

The principle of the gauge under discussion is shown in the diagram Fig. 162. The hatched portion represents the section of a commutator segment. In trigonometrical language, the line *b c* represents the "cotangent" of the angle *c a y*, otherwise denoted by the letter θ, which is the angle of the strip. The radius *a b* is unity. It will thus be observed that the taper of the section may be expressed in terms of the gradient of the line *a c*, as compared with the horizontal line *x y*, obviously to be determined by the number of times *a b* will "go into" *b c*. Assuming a 40-part commutator, when θ will be 9°, and making use of a table of natural sines, we find the numerical value of the cotangent *b c* for the angle $\theta = 9°$, to be 6·3138. The line *a b* being unity, the gradient of *a c* will thus be 1 in 6·3138, which may be given as the taper of the segment.

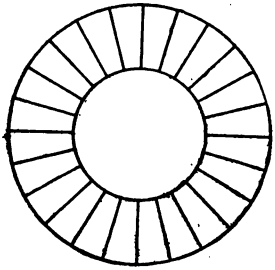


FIG. 160.

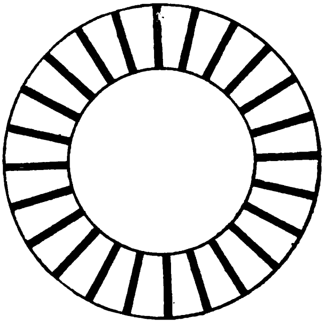


FIG. 161.

It so happens, that for any number of segments in a commutator, from about 40 up to 160 or 180, if the number of segments be divided by the corresponding numerical cotangent of the angle of one of them, a constant, 6·3, is arrived at when not exceeding one place in the decimals. This is, therefore, useful, since by simply dividing the number of segments by this constant, we arrive at the taper in terms of a gradient.

Referring again to Fig. 162, it will be observed that the triangles *a b c* and *a c y* are similar; and $c\,y = a\,b$, and $a\,y = b\,c$. It is also obvious that if we shorten the parallelogram *a b c y* by moving *c y* nearer to *a b*, we shall open the angle θ; and *vice versâ*. Conversely, if the angle be opened *b c* will become shorter, and if θ be closed *b c* will lengthen. Thus for a large number of segments, and consequently a small angle θ, *b c* and *a y* will be much longer than with a small number of segments and consequent large angle. Now *a b* being unity, so also is *c y*. The distance of *c y* from *a b*—that is, the length of the cotangent *b c*—may be calculated for every feasible number of segments in a commutator in the manner stated above—that is, by dividing the number of segments in each case by the constant 6·3. This being done, the various points where *c y* will stand on *a y*, in accordance with the number of segments and consequent size of angle θ, may be marked on *a y*, and the corresponding number of segments figured on also. A scale will thus be formed on *a y*. Subsequently, in order to fix *a c* at the proper slope for any number of segments, it will be merely necessary to make *c y* stand perpendicularly on the mark on the scale having that number.

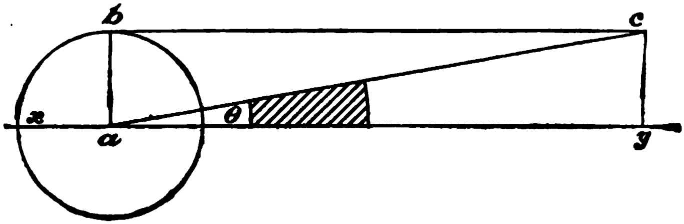


FIG. 162.

It is in this manner that the scale on the gauge under discussion is formed, with a standard unit (corresponding to *c y*, Fig. 162), of one inch. Hence, to use the tool, a flat standard inch gauge, held perpendicular to the edge of the scale, is placed between the jaws exactly at the mark denoting the number of segments. This sets the gauge open at the required angle or taper. In giving instructions, the distance of the inner edge of the segment from the centre (*a*, Fig. 162) may also be given; though this must be the small radius with the insulation absent, as shown and explained in connection with Fig. 160. Thus the taper and thickness of the segment are both stated. The gauge, after having been set, is fixed by the fly-nut and cross arm, as shown in the illustration.

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